

**Prehistoric Coastal Archaeology of the
Farasan Islands, Saudi Arabia**

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Abstract

Despite being the oldest multidisciplinary archaeological discipline the study of coastal archaeology and shell mounds has received relatively little attention until recently. The recognition of the importance of coastal resources from the Holocene back into the Palaeolithic has resulted in a new focus on the theme. One of the key questions is how far coastal resource exploitation goes back and whether what we see now is purely a product of Holocene intensification.

The Arabian Peninsula has received relatively little attention and the role of coastal economies in the history of the region is poorly understood compared to many areas. The recent discovery of one of the highest densities of shell midden sites in the world provided the opportunity for these questions to be addressed. A multidisciplinary project using both state of the art and tried and tested methods resulted in the discovery and mapping of nearly 3000 shell midden sites and extensive coastal change on the islands.

This thesis found compelling evidence for a short burst of intensive shellfish exploitation and site accumulation, the culmination of a long history of shell midden formation in the region going back into the early Holocene. Excavation of several sites allowed the formation processes of large shell mounds to be assessed, which is another question central to shell midden research. Geoarchaeological investigations have put these processes into context with coastal change to determine that exploitation was taking advantage of a small window of ecological opportunity. Dating methods have also been scrutinised, with a new value for local Marine Reservoir Effect determined, and Amino Acid Racemization calibrated for the region and tested.

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Authors Declaration

The majority of the work presented in this thesis has been undertaken by the author and is original. Fieldwork was completed as part of a team under the Southern Red Sea Project in March 2008 and 2009; elements of this have been published (listed below). The sorting and measuring of bulk samples is an ongoing collaboration being undertaken with the kind help of Dr Eva Laurie; this work is unpublished. Amino Acid Racemization dating is part of a collaboration in the Bioarchaeology Group, with training and guidance provided by Dr Kirsty Penkman and Dr Beatrice Demarchi; preliminary work has been published in a joint paper (listed below).

Overviews of this research project have been presented in the following places (Demarchi *et al.* 2010 is included in the Appendix):

Academic Publications

- | | |
|---|---------------|
| Demarchi, B., Williams, M.G.M., Milner, N., Russell, N., Bailey, B., Penkman, K. (2010) Amino acid racemization dating of marine shells: a mound of possibilities. <i>Quaternary International</i> . 239(1-2): 114–124. | 2010 |
| Williams, M.G.M. (2010) Shell mounds of the Farasan Islands, Saudi Arabia. <i>Proceedings of the Seminar for Arabian Studies</i> 40: 357-366. | 2010 |
| Bailey, G. Williams, M., Al-Sharekh, A. Shell middens and shell mounds above and below sea level in the southern Red Sea. In G. Bailey, K. Hardy, A. Camara (eds.) <i>Shell energy: coastal resource strategies</i> . Oxford: Oxbow | Accepted |
| Williams, M.G.M. (2011) Fisher-Gatherers of the Red Sea: Results of the Farasan Archipelago Shell Sites Project. <i>Proceedings of ICAZ 2010. British Archaeological Reports</i> . | Accepted |
| Alsharekh, A., Bailey, G.N., Momber, G., Moran, L.J., Sinclair, A., Williams, M.G.M., Laurie, E., AlShaikh, N., AlMa'Mary, A., AlGhamdi, S. Coastal archaeology in the Farasan Islands: report on the 2008 fieldwork of the joint Saudi-UK Southern Red Sea Project. <i>Atlat: Journal of Saudi Arabian Archaeology</i> . | In prep |
| Bailey, G.N., Alsharekh, A., Momber, G., Moran, L.J., Williams, M.G.W., Satchell, J.S., Gillespie, J., Reeler, C., AlShaikh, N., Robson, H. Coastal archaeology in the Farasan Islands: report on the 2009 fieldwork of the joint Saudi-UK Southern Red Sea Project. <i>Atlat: Journal of Saudi Arabian Archaeology</i> . | In prep |
| Williams, M.G.M. (2009) <i>Shell Middens in the Red Sea</i> . Mesolithic Miscellany 19:2 | 2009 |
| Quaternary Research Association – Annual Discussion Abstracts 2009 and 2010 – Abstracts for papers presented at the QRA ADMs. | 2009 and 2010 |

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Academic Presentations

<i>Mid-Holocene Palaeocoastlines of the Red Sea – Evidence for Hydro-isostasy, Tectonics or both?</i>	Sep- 2011 Speaker	All At Sea
<i>Fisher-Gatherers of the Red Sea: Results of the Farasan Archipelago Shell Sites Project</i>	Aug- 2010 Speaker	ICAZ 2010
<i>Fisher Gatherers of the Red Sea</i>	Jun- 2010 Speaker	University of York Research Forum
<i>Human Responses to Mid-Holocene Sea Level Fluctuations in the Southern Red Sea</i>	Jan- 2010 Speaker	QRA Annual Discussion Meeting 2010
<i>An Evaluation of Shell Site Evolution</i>	Dec- 2009 Speaker	University of Edinburgh Guest Speaker
<i>Shell mounds of the Farasan Islands, Saudi Arabia</i>	Jul- 2009 Speaker	Seminar for Arabian Studies 2009
<i>FARSSite- The Farasan Archipelago Shell Sites Project</i>	Jun- 2009 Speaker	University of York Research Forum
<i>FARSSite- The Farasan Archipelago Shell Sites Project</i>	May- 2009 Speaker	Gathering Our Thoughts, Mesolithic Postgrad day
<i>Geoarchaeological Investigation of Shell Mound Evolution in the Farasan Islands</i>	Jan- 2009 Speaker	QRA Annual Discussion Meeting 2009
<i>Shell Mound Distribution on Dynamic Coastlines and the Composition of Mound Sediments</i>	Apr- 2008 Speaker	Shell Energy Conference - Senegal
<i>FARSSite – The Farasan Archipelago Shell Sites Project, Saudi Arabia</i>	May- 2009 Poster	Prehistoric Europa Conference
<i>Palaeoshorelines in the Red Sea</i>	Sept- 2010 Poster	PALSEA Conference

Chapter 1

Introduction and Background to Coastal Archaeology

1. Introduction and Background to Coastal Archaeology

1.1 Introduction

This thesis aims to shed light on the great unknown areas of prehistoric coastal exploitation of the Red Sea, on the Farasan Islands. Very little work has been undertaken in the region, with the few surveys commissioned only hinting at the nature of the archaeological deposits present on the islands (eg Zarins *et al.* 1981; Zarins and Al-Badr 1986). This all changed in 2006 when the archaeological potential of the islands was first recognised and published (Bailey *et al.* 2007a). This PhD project arose from this opportunity, specifically tasked with investigating the high density of prehistoric Holocene coastal sites on the islands. The specific aims of the project are to investigate the distribution, timing and intensity of shellfish exploitation; to explore the phenomenon of the emergence of large shell mounds, and to explore social and economic responses to environmental change.

Shellfish have a long history as an important food source, with several significant Palaeolithic sites showing continued exploitation, even when the coastline was not in the immediate vicinity of the sites (eg Blombos, Henshilwood *et al.* 2001; and Pinnacle Point, Marean *et al.* 2007). A small number of sites bridge the time-span from these early sites up until the stabilisation of modern sea levels around 6000BP. Holocene shell midden sites are known across the world on almost every inhabited shoreline, showing the importance of this resource to coastal communities. Some regions are less intensively studied, and less is known about them, for example along the Red Sea. However what little work has been undertaken has shown a number of mid-Holocene shell midden sites to be present.

There are two theories regarding the origin of global shellfish exploitation: The first suggests that intensive shellfish exploitation is a Holocene adaptation, after sea levels had stabilised allowing productive shell beds to form. The second theory is that shellfish gathering has always been an important subsistence strategy, from the Palaeolithic to the Holocene,

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however sites pre-dating the mid-Holocene are archaeologically less visible because they have been inundated by rising sea levels. Only where vertical movement of the land surface has intervened, or the shoreline is steeply sloping, are earlier sites found.

Another key issue is understanding the formation processes at work within shell middens. Compared to other types of site very little work has been undertaken to decipher how these sites emerged. This theme is coming to the fore, with a couple of recent studies shedding some light on the area and putting forward some convincing theories (Briz *et al.* 2011; Russo and Heide 2003). The formation processes and rates of deposition of a shell mound link directly into the question of whether shell mounds emerge as the result of short periods of intensive exploitation or longer periods of lower level activity. Only excavation can answer this question, since it is the only way to fully assess the deposit.

A core element in the investigation of shell middens are the socio-economic responses to climate and sea level change. Large shifts in both are not limited to the Holocene, as the climate is in a constant state of punctuated equilibrium. Quantifying these is hard, but new developments in technology are allowing higher resolution investigations, as demonstrated by a number of researchers in Northern Europe (eg de Pablo and Puche 2009).

The Farasan Island shell middens are uniquely positioned to allow analogies to work in other regions of the world, whilst also increasing knowledge of a region which has up until now received relatively little attention. The number of sites on the islands suggests an intensification through the Holocene, however the region is tectonically active, raising the possibility of earlier sites on tectonically uplifted coastlines.

Palaeoshorelines identified on the islands and in the region hint tantalisingly at this prospect. Any additional information gained about the sites and archaeology of the islands will be new and important work.

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Determining the distribution of sites on the islands, exploring their processes of formation, and dating both lines of evidence will provide answers to the questions raised earlier in this section. Namely this is whether there was an intensification of shellfish exploitation during the Holocene; what the social and economic responses to climate and sea level change were; and what shell midden formation processes were at work. These questions are interlinked by the themes of site distribution, dating, composition and internal structure.

The distribution of the sites will inform on how the sites relate to their environment, for example their association with palaeoshorelines. Their composition and internal structure will relate both to their formation processes (both pre and post-deposition), and their relationship with the local environment and any changes that may have occurred in it (such as climate change, or shifting coastlines). Dating these deposits will allow an assessment of whether sites within the same group relate to the same phase of accumulation, and also the temporal relationship between different groups of sites. This will help to answer the question of Holocene intensification, and also to identify social and economic responses to climate and sea level change. Finally dating the internal structure of a shell midden will allow the rates of formation to be assessed, and to determine whether any changes in the internal structure or composition are related to socio-economic responses to environmental change. It will also allow an assessment of whether exploitation intensified over time.

The Farasan Islands sites are therefore vital to answer questions both at a regional and global level. Their abundance and excellent preservation offer an unparalleled opportunity to carry out the necessary research, and be able to select sites best suited to answer these questions. Many studies are often restricted in what they can answer by the nature of the archaeology. Preliminarily these sites are very promising.

This brief outline highlights some key areas in need of further research which the Farasan Island sites give the opportunity to investigate. These

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have been translated into the following research questions with associated objectives. The first task is to determine the spatial and temporal extents of the sites. The next approach would be to provenance the sites and gain an understanding of when they accumulated; this would enable them to be associated with the regional and global contexts.

To put these sites into context the first research question must be:

- Are the Farasan Island shell sites the result of a short period of intensive exploitation or a longer period of lower level activity?

This has a number of associated objectives which must be met:

- Map the location of shell midden sites
- Sample selected sites for dating and to determine internal composition/structure

Large shell mounds are also well placed to answer this primary research question. In addition a number of outstanding issues which have relevance both locally and to broader shell midden research can also be encompassed under the next research question:

- Why do large shell mounds emerge in this region?

The associated objectives target specific questions which have wider significance to shell midden research:

- Establish the processes of formation by determining the internal structure and composition of a large shell mound site by excavation
- Quantify the rates of formation by initiating a dating program of the internal structure to investigate the temporal evolution

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- Conduct geoarchaeological investigations in order to assess the relationship between site formation and the ecological and geological dynamics of coastal change
- Explore the social and economic activities associated with the emergence of such sites and in the broader landscape

This also ties in with the first aim and associated objectives, which help define the spatial distribution of sites and composition of surrounding sites. Large sites can accumulate rapidly or slowly in line with the first research question.

The following section will put the research questions into context, detailing the significance of coastal resource exploitation, and the previous work undertaken which has demonstrated this. Several key research questions remain outstanding in this field of work, which this thesis aims to address to highlight the significance of the research.

The two subsequent chapters will first address the regional archaeological context in which the Farasan Island shell sites accumulated, followed by their climatic context (Chapters 2 and 3).

Methods and results have been packaged together to address the specific themes of site intensification and distribution, formation processes, timings, broader site relationships and underlying environmental change (Chapters 4-8). These are drawn together to address social and economic factors (Chapter 9), before leading into a broader discussion on the results (Chapter 10). Finally the Chapter 11 addresses the conclusions.

1.2 Background to the Research

1.2.1 Background to Coastal Archaeology

Before investigating the issues behind the research aims in more detail it would be useful to review the background of coastal archaeology, in order to put this research into the broader context. Many of the underpinning themes are broadly relevant to the research area and period of study.

The use of coastal resources in prehistory was important in many areas. The long history of human coastal (and aquatic) resource exploitation is well established and has been the subject of much debate (eg Erlandson 2001; Verhaegen and Munro 2011). Indeed this thesis was born from investigation of the Farasan Islands by the Southern Red Sea Project in search of Palaeolithic sites (Bailey *et al.* 2007a). In the 1960's the Aquatic Ape hypothesis (Hardy 1960) was a revolutionary concept for the development of bipedalism through contact with water (Morgan 1982). Although the field has moved on from this theory (eg Young 2008; Young *et al.* 2010), the idea of water playing a key role in the development of anatomically modern humans has remained a central theme (eg Braun *et al.* 2010). This is due not only to the human need to consume water each day (eg Newman 1970), but that most other living organisms regularly do as well. This results in a wide range of flora and fauna taking advantage of and converging at places where water is readily available, making these areas more species diverse. For a genus such as *Homo*, this equates to a congregation of readily available resources, even if predatory species might be present. Many of the oldest archaeological sites are in areas where water was readily available, whether lakes, ponds, or rivers (such as Boxgrove, Roberts and Parfitt 1999; Semliki, Brooks *et al.* 1995; Yellen *et al.* 1995). However archaeological visibility could play a key role in this scenario. Wet areas have a better preservation potential, as artefacts and remains can quickly become buried beneath depositional sediments, often before decomposition or scavenging can take place. Water-logging in turn can reduce oxygen

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availability to decomposing organisms, which allows for better preservation (eg Holden *et al.* 2009). Water edges can also have increased rates of erosion, this can destroy sites soon after they are created, or it can expose material previously buried, increasing archaeological visibility for a period of time before reburial or erosion.

Aquatic environments offer unparalleled resources on a range of scales, and require a range of technologies to access. Fertile hinterlands can offer numerous opportunities for foragers using minimal technology, from gathering edible plants, to building material. A number of species of shellfish can be gathered by hand from shallow water; fishing requires more advanced hunting strategies, whether this is the construction of traps, the use of nets, or hooks and spears, but equally can also take place in rock pools where fish can become stranded by the ebbing tide (Bailey *et al.* 2007b; Fa 2008).

Coastal environments can often offer all of the advantages of aquatic environments, and more. The shoreline can offer shellfish, drift wood, or even the carcasses of stranded sea creatures. Additionally estuaries and lagoons can attract a wealth of flora and fauna, some of which require minimal technology to gather, whilst others may require hunting technologies to exploit. There is also increased availability of fresh water. It has been suggested that during periods of lower sea level – which accounts for nearly 90% of the Quaternary (eg Elderfield *et al.* 2006), the potential for freshwater availability on the continental shelves greatly increased. This is known as the *Coastal Oasis Theory*, and suggests that lowered sea level would have reduced the loading on the continental shelves, and thus increased the hydrostatic head of water stored in aquifers (Faure *et al.* 2002). This would result in increased outflow from these sources onto the exposed continental shelf, making them much more attractive places for flora and fauna, and crucially humans. In addition climate is thought to have been more arid during glacial conditions (eg Faure *et al.* 2002); thus for much of the Quaternary conditions would have been favourable for hominin occupation both on

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the continental shelves and their coastlines. For this study this is particularly relevant since sea level stabilised at c.6000BP, yet earlier coastal sites have been found meaning that communities already existed which had a coastal adaptation.

Coastlines are varied environments and can change spatially as much as they do temporally. Embayments and estuaries can accumulate deep sediments, perhaps burying sites forever, whilst other stretches of coastline may experience constant erosion. Coastal stability can be categorised as stable, such as rocky shorelines, intermediate, such as open coastlines, and rapidly changing, such as estuaries. This will affect the degree to which archaeological sites are preserved, and are visible.

The oldest evidence of aquatic or marine resource exploitation comes from the site of Terra Amata on the French Mediterranean, dating back to c.300K BP (Lumley 1966). This open-air site contained shellfish and fish bones spread across what has been interpreted as a tent with a hearth in at the centre. Bioturbation is thought to have taken a serious toll on this site, time averaging the deposits (Villa 1983; Balek 2002). If bioturbation was not responsible for introducing the shells into the stratigraphy, this site represents the earliest evidence of coastal resource exploitation.

It is not for another c.150K years that coastal sites appear in Africa, at Pinnacle Point dating to 164-40 BP (Marean *et al.* 2007). Broadly contemporary with this is Blombos Cave at 140-30K BP (eg Henshilwood *et al.* 2001; Jacobs *et al.* 2006) which is the first true shell bearing archaeological deposit, containing a substantial proportion of shell within the sediment. These sites demonstrate the adaptability of humans at the time and taking advantage of rich marine resources available locally. Indeed a prominent school of thought is that aquatic and marine resources played a key role in human evolution, particular the development of the brain (Cunane and Stuart 2010; Erlandson 2010b).

The oldest known fishing implements come from a freshwater site in the

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Democratic Republic of Congo, where worked bone artefacts, interpreted as harpoons or barbed spears, have been found in association with catfish bones (Yellen *et al.* 1995). Known as the Semliki assemblage, these date back to 90k BP. Marine fish bones are found in association with shellfish such as at the aforementioned Blombos Cave (Erlandson 2001; Klein *et al.* 2004). This indicates that even given the wide temporal and spatial distribution in the archaeological record between sites, marine and aquatic exploitation is a recurring theme in the Middle and Lower Palaeolithic. These early sites demonstrate that anatomically modern humans (AMH) were already exploiting coastal resources at these early times, therefore it would be expected that sites dating to before c.6000BP and modern sea level would exist if humans were present in a given area.

Current evidence suggests that AMH began moving out of Africa between 120kBP and 40kBP (eg Klein 2000; Stringer 2000; Derricourt 2005; Mellars 2006; Shea 2008). Much of this evidence is inferred from assumptions about the rate of mutation in DNA (eg Watson *et al.* 1997; Quintana-Murci *et al.* 1999; Kivisild *et al.* 2004; Forster and Matsumura 2005). The reliability of genetic dating techniques has been questioned (eg Roger and Hug 2006; Endicott *et al.* 2009), with an increasing number of earlier lithic bearing sites claiming to be associated with AMH. Jebel Faya and Jubbah are two such sites, indicating a presence on the Arabian Peninsula at c.125-90kBP and 75kBP respectively (Armitage *et al.* 2011; Petraglia *et al.* 2011; see also Wahida *et al.* 2009).

By 60kBP AMH had reached Australia suggesting a coastal adaptation was sufficiently advanced to allow transit across permanent sea barriers (eg Bednarik 2003; Davidson 2010; Flemming *et al.* 2003). This encompasses both the technology to create a vessel capable of sustaining life at sea, and also the aptitude of the sea farers to voyage beyond the visible horizon. Supporting the Australian dates are evidence from areas such as the Bismark Archipelago and Solomon Islands which show a presence at 40-30kBP both necessitating 80-90km sea voyages (Anderson *et al.* 2010; Erlandson 2010a). Whether the crossing of the

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Bab-al-Mandab into the Arabian Peninsula necessitated a sea crossing or a longer circuitous journey by land is discussed in a number of papers (eg Bailey *et al.* 2007a, 2007b), and will likely remain a topic of debate.

Although deliberate movements have been suggested there is also a strong argument for accidental migration. This might be people being washed out to sea on rafts of entangled vegetation, whether by flash flood or tsunami, or fishermen straying off course or getting taken out to sea by a storm (Anderson *et al.* 2010). Any range of factors might have resulted in a small, but viable population making it across sea barriers against their will.

The early dates for AMH outside of Africa strongly suggest that they would have passed, and perhaps settled along the Red Sea; the early sites on the Arabian Peninsula are certainly very suggestive. If the coastal oasis theory is correct and applicable to the Red Sea earlier sites are likely to be submerged on inundated palaeoshorelines.

Palaeolithic sites which exhibit evidence of coastal resource exploitation, specifically of shellfish and fish could represent a specific adaptation; alternatively they could be opportunistic scavenging of the foreshore (Bailey 2009). The most enduring, and usually the most obvious, indicator of coastal resource exploitation is the presence of shellfish. These are most commonly manifested as shell middens. Shellfish exploitation is by no means the only form of coastal specialisation, although it is often seen as one of the simplest (eg Bailey 2007). Shell middens rarely contain only shell, although this is often the most obvious constituent in archaeological sites. It is very rare for sites to contain only shell, but not unknown (eg Alsharehk *et al.* in press; Williams 2010).

By their very nature shell middens are more enduring than other forms of sites, since shell is much more resistant to diagenesis than many other materials deposited at human habitation sites (Stein 1992; Claassen 1998). When these sites are found located in more stable environments,

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such as within caves or rock shelters, their preservation potential increases even more. There are many famous examples of cave sites with long sequences back into the Palaeolithic (eg Blombos, Jacobs *et al.* 2006; Pinnacle Point, Marean *et al.* 2007). In other locations shell mounds can be as vulnerable to time averaging and destruction as any other sites. On dynamic coastlines this vulnerability is increased, as sites can easily be eroded, or buried under many metres of sediment (Van der Schriek *et al.* 2007a, 2007b, 2008). The onset of farming has posed a new risk to shell middens, as farmers find the material favourable for application to their fields (eg Hardy and Wickham-Jones 2009). Shell also makes an excellent supplementary material for building construction, and many shell mounds have been destroyed for this purpose (eg Camara in press).

A key question is *when is a shell midden a shell midden?* And when is it a shell bearing deposit? The defining feature of a shell midden is that it has predominant shell clasts in a matrix, which is often composed of broken or small shell. This does not exclude the possibility that there are layers within the site which are free from shell; neither does the matrix of the shell bearing sediments have to be completely composed of shell. A shell bearing deposit is an archaeological deposit containing quantities of shell that are not the primary constituent; although individual layers dominated by shell may be present within the deposit and are often referred to as shell midden layers.

Some archaeological sites contain very few shells, for example the Upper Palaeolithic levels of the La Riera Cave site in northern Spain yielded 19,600 shells, deposited over a 10K period between 23-13K BP, which is an average of nearly two shells a year (Straus and Clark 1986; Ortea 1986). The Middle Palaeolithic site of Moscerini Cave in Italy yielded 401 shells which accumulated over 55K between 115 and 60 K BP, averaging 1 shell in nearly 140 years. Pinnacle Point has yielded abundant quantities of shell, although these were distributed through the site with up to 240 in any one deposit (Marean 2010; Jerardino and Marean 2010).

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By comparison the larger Holocene sites such as the Australian Weipa mounds, Brazilian Sambaquis, or San Francisco shell middens contain many hundreds of thousands to millions of shells (eg Bailey 1993; Gaspar 1998; Luby and Gruber 1999).

The pre-Holocene sites described above are clearly not shell middens, because the amount of shell in the deposits is not dominant, and is not a key component of the matrix, but they are important evidence of coastal exploitation. The Holocene sites show a marked increase in the abundance both of shell bearing sites, and shells within sites, which would seem to indicate an intensification of shellfish exploitation. This phenomenon is seen worldwide, on every inhabited continent (eg Rowley-Conwy 1983; Inskeep and Vogel 1985; Schulting 1996; Gaspar 1998; Russo and Heide 2003; Vermeersch *et al.* 2005a; Biagi 2006; Fischer *et al.* 2007; Van der Schriek *et al.* 2007b; Colonese *et al.* 2009; Hardy and Wickham-Jones 2009; Villagran *et al.* 2011; Clemente-Conte *et al.* in press; Moustapha in press).

There are very few sites which contain this magnitude of shells prior to the onset of the Holocene, with the exception of a few sites such as Blombos, (Henshilwood *et al.* 2001; Jacobs *et al.* 2006). It therefore appears that during the Pleistocene there was constant low level shellfish exploitation around the inhabited coastlines. This formed a small part of a much broader exploitation strategy of those populations (eg Bailey 1975, 1977; Osborn 1977; Parmalee and Klippel 1974).

With large scale climate and sea level change into the Holocene, intensive shellfish exploitation may have been a key social and economic response, perhaps taking advantage of periods of stability when shellfish were more abundant and a more reliable source of food. The alternative possibility is that earlier shell middens created by intensive exploitation were deposited at a time when sea levels were lower than their current level and have either been destroyed by rising sea levels, or are archaeologically less visible below the waves. Social and economic

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responses to changes in climate and sea level are another gap in current research knowledge which is to be addressed in the research aims of this thesis.

The Pleistocene is characterised by glacial conditions, punctuated by a series of warmer interstadial conditions (eg Petit *et al.* 1999; Clark *et al.* 2006). The termination of these glacial conditions marked the onset of the Holocene, characterised by climate amelioration and the contraction of the vast ice sheets which covered the Northern Hemisphere. The melt water from these events raised the level of the oceans by up to 120m, as shown in Figure 1 (eg Lambeck *et al.* 2002). This had two marked effects: notably warmer temperatures and increased precipitation, and secondly a reduction of the continental shelf.

The degree to which this affected the area of territory habitable to humans is dependant on the region. In most locations ameliorating climate would have improved conditions in the interior, with wetter, milder conditions supporting greater flora and fauna, and increasing water availability. This is likely to have offset the loss of the continental shelves by creating new habitats inland as habitats on the coastal plains were lost.

It is likely that many earlier archaeological sites would have been located on the continental shelf, and would have become inundated by rising sea levels, making them archaeologically less visible. The action of waves moving over sites as sea level rose, or exposure of the sites to currents could also have resulted in them becoming reworked and ultimately destroyed.

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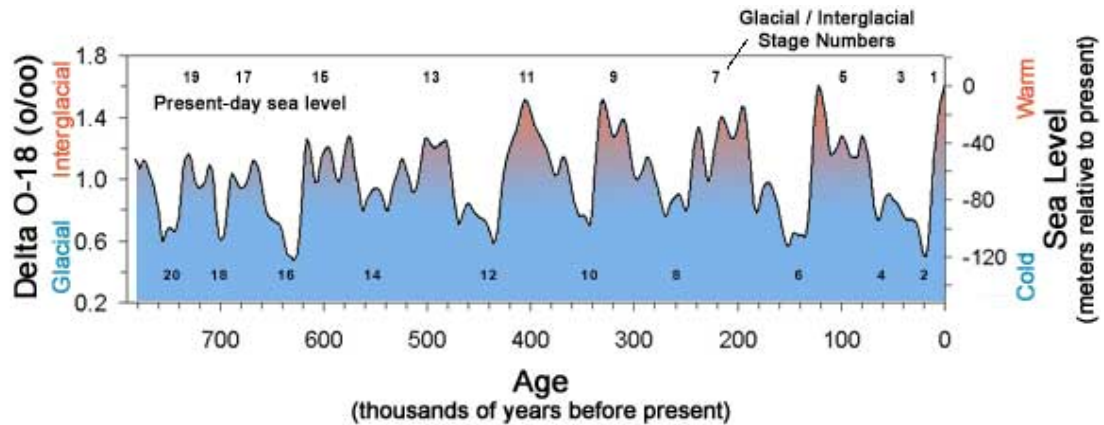


Figure 1: Oxygen Isotope and Sea Level Change (Imbrie *et al.* 1984).

As has been demonstrated, climate is by no means static, meaning that areas which might today seem unfavourable for human exploitation may have been attractive areas in the past (see Faure 2002; Bailey *et al.* 2007b). Intrinsically related to this is that sea level has rarely been static for extended periods, therefore the time available to form archaeological deposits has been much reduced when compared to the situation today. Many mid-late Holocene sites have experienced stable sea levels allowing deep stratified archaeological deposits to accumulate at the shoreline over many generations. However if sea level were to change, accumulation at these sites would likely stop and begin on the new shoreline. If the shoreline is not static for long periods it will not be possible for deep deposits to accumulate. These sites will therefore be archaeologically less visible. The exception to this is locations which present additional benefits, the best example being cave sites. However there is debate as to whether these sites offered greater benefits as *home-base* locations or whether they are simply better preserved than open air sites.

The review of global evidence for coastal exploitation informs on the research aims of this project. The distribution and size of sites is likely to be affected by changes in sea level, with the largest sites emerging after the stabilisation of sea level c.6000BP. It suggests that intensive mid-Holocene shellfish exploitation was a development of earlier subsistence strategies. However, evidence of earlier shellfish exploitation may be

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archaeologically less visible due to sea level rise. These are areas which require further research to determine social and economic responses to shifting conditions, and to examine whether shellfish exploitation has intensified or whether the same changing conditions have resulted in a more dispersed record. The next section will focus on Holocene shellfish exploitation, and what current work has revealed about its extent and nature.

1.2.2 Intensification of Holocene Coastal Resource Exploitation

The quantity and size of mid-late Holocene coastal sites dwarfs that of any preceding period. A number of theories have been put forward to explain this; these can be broadly put into two categories. 1. That coastal exploitation intensified during the mid-late Holocene; and 2. That previous evidence is archaeologically less visible, being underwater.

The second hypothesis links directly into the discussion on sea level change outlined previously: that sea levels have been lower than present for the majority of the Quaternary, and therefore the majority of early and pre-Holocene sites will be below sea level. This argument requires that coastal exploitation has been an active subsistence strategy of coastal dwellers prior to sea level stabilisation in the mid-Holocene; a number of high profile sites lend plausibility to this idea (eg Ortea 1986; Henshilwood *et al.* 2001).

The first hypothesis does not discount that humans were exploiting the coastlines before 6000BP, but it does suggest that this was at a level lower than in the Holocene. A number of reasons why exploitation might intensify have been put forward including:

- Population increase and the need to find alternate food sources.

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- Ecological windows of opportunity opening as flooded areas became productive shell beds, accentuated by climate amelioration (Bailey *et al.* 2007b).

A factor accentuating the intensification described above would have been the rising sea levels. Populations would have been forced progressively further up the continental shelf as sea level rose. They would have found their ranges becoming smaller and population densities steadily increasing. If the *Coastal Oasis* theory is correct, the situation would have been compounded, since the continental shelf would potentially have been a much more attractive environment than inland, supporting higher population densities than the interior. With these communities forced into a smaller range, with fewer resources the carrying capacity of the land would have been reached and passed. Therefore one response would have been the intensification of coastal exploitation, notably shellfish. The communities would already have been aware of these resources, and would most likely have exploited them before at lower intensities, as demonstrated by the few Palaeolithic sites. However as sea level rose, so climate would have been ameliorating, and the previously arid hinterlands would have, at least in many parts of the world, become more productive and better watered, thus offsetting the loss of coastal territory.

Rising sea levels would have been creating and destroying habitats along the coastlines of the world. However the sea level rise of 120m was not a gradual steady rise; neither was it a sudden inundation (eg Turney and Brown 2007). Instead it would have been a series of smaller inundations punctuated by periods of stability, and would have been locally very variable. The length of stable periods would have been variable, as would the intensity of the rises, with some larger than others (Turney and Brown 2007). During each phase of stability new ecological habitats would have been created, presenting unique exploitation opportunities. The visible Holocene shell middens might represent the final phase of this, when sea level stabilised at about the present level. These shell middens formed

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adjacent to productive shell beds, many during short windows of opportunity. One such example is the Muge shell middens in Portugal, which were once situated above a productive tidal mudflat that has been superseded by an alluvial floodplain. These sites were used for c.2000 years coinciding with the establishment of the shell beds, and abandoned when the local estuarine environment contracted, which impacted upon the productivity of the shell beds (eg Van der Schriek *et al.* 2007a, 2007b).

Archaeological visibility and taphonomy of sites is important in explaining the appearance of large shell middens during the Holocene. There may well have been a much longer history of intensive shellfish exploitation which stretches back into the Pleistocene. However sea level has only been at its current level since c.6000BP and it has not been at this level since c.125kBP during MIS5e (eg Lambeck *et al.* 2002), therefore any sites dating to c.125-6kBP which were not located above present sea level will be submerged on palaeoshorelines. Sites relating to MIS5e are of such great antiquity that both taphonomic and environmental processes are likely to have obscured these from the archaeological record, with the exception of some sites located in caves.

This theory is supported by sites such as Blombos Cave and Pinnacle Point, which are located close to the modern shoreline, and would therefore most likely have been close to the MIS5e shoreline. The Spanish sites have similar situations (eg Ortea 1986), where they are located on steeply sloping coastlines. These sites all show evidence of coastal exploitation well before modern sea levels were established. Indeed it has been shown that the concentrations of shellfish within deposits such as La Riera and Balmori are proportional to the changing distance from the shoreline as sea level rose (eg Bailey 1983; Bailey and Craighead 2003). One explanation why the sites are not on the same scale as those of the Holocene might be that these sites have been affected by taphonomic processes, time averaging deposits that were once more substantial. Or perhaps populations were smaller and

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gathered marine resources less intensively.

There are anomalies in the appearance of higher intensity shellfish gathering at 6000BP. In some regions sites appear earlier and are currently above sea level. Sites such as An-Coran (Hardy and Wickham-Jones 2009) in Scotland are dated to 7660BP, Druimvargie to 8340BP (Bartosiewicz *et al.* 2010), and Sand (Hardy and Wickham-Jones 2009) are all above present sea level, when it would be expected that they should be submerged. This can be explained by isostatic rebound (eg Gehrels 2010), which has resulted in the local land surface uplifting at a faster rate than sea level. During glacial maxima the weight of ice sheets pushed the land surface down into the lithosphere. This displaced the lithosphere, causing it to rise where the ice sheets terminated, in what is called a *fore bulge*. When the ice melted the land surface returned to equilibrium (its position before the ice) resulting in the collapse of the fore bulge, and rise of the depressed land surface below the former ice sheet (eg Firth *et al.* 2010). In the case of Scotland, an extensive area was covered by an ice sheet during the LGM; as a result the land is still rebounding, impacting on the archaeology. The sites mentioned above have been afforded protection from submersion and erosion, since the uplift of the land surface was equal or greater to sea level rise. In addition these sites have experienced a longer time frame in which to accumulate, because the local coastline would have been kept more stable and at a near constant distance from the shoreline.

These sites suggest that intensive shellfish gathering occurred earlier in the Holocene, supporting the theory of pre-adaptation. Our understanding of the processes affecting shell middens before, during and after inundation is incomplete, and little is known about how waves, currents and tides would erode and redistribute midden material. What is certain is that few submerged sites have been found, with the notable exception of the Baltic, where favourable conditions have resulted in the excellent preservation of many sites of the Ertebølle culture (eg Raemaekers 1997).

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In other areas the shoreline would have been changing at a faster rate, with ecological conditions allowing single species to dominate temporarily. This may have resulted in relatively short periods of ecological productivity, reducing the length of time for exploitation and site formation. In addition the location of prime sites for occupation would also have been changing with these changing conditions. Sites next to productive shell beds for a longer period of time are more likely to accumulate larger deposits. These deposits are more resistant to taphonomic processes, and therefore more likely to be visible in the archaeological record.

Centrally important in this is the stability of the coastline. As described above the Scottish coastline, through a number of factors, has been stable for an extended period of time. It should also be noted that the locations of many of these sites are on rocky coastlines in the relative shelter of the Hebrides, and that many sites are located in caves or within rock-shelters. These offer added protection from the elements, and have contributed to the archaeological visibility of these sites. Sites situated on the open coastline with less protection may be eroded, or buried by deposition. Estuarine sites are prone to the dynamic nature of the local environment, and may be eroded by shifting channels, or buried beneath many metres of sediment (Van der Schriek *et al.* 2007a, 2007b, 2008).

What features might submerged sites exhibit? Given the nature of most of the majority of Holocene shell middens, they would be expected to display similar characteristics, and be composed of a variety of material derived from both marine and terrestrial resources. This is certainly the case in many of the Danish sites, where many have excellent preservation especially of organic material (eg Kubiak-Martens 1999). These sites must have been inundated soon after abandonment and rapidly covered in a layer of protective sediment in a relatively low energy environment. The degree to which sites are preserved will be dependent on:

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- The time lag between site abandonment and inundation
- The length of occupation and activities carried out – thus depth and constitution of deposit
- The energy level of the environment
- The rate of sedimentation

Very few places will achieve perfect conditions for preservation and archaeological visibility as outlined above. Sites are normally only discovered when a change in the local energy level or sedimentation rate expose and erode the site, the two are usually intrinsically linked. Thus the exposure of a site will be quickly followed by its erosion.

The question of whether older sites exist below sea level is a contentious one, since little evidence has been found to support it (eg Erlandson 2001; Bailey and Craighead 2003; Erlandson and Fitzpatrick 2006; Bailey *et al.* 2007a; Bailey *et al.* 2007b). However, given the longevity of coastal resource exploitation it is hard to imagine that it was not an important strategy prior to 6000BP. Ethnographic work suggests that foragers are unlikely to carry shellfish further than necessary, which is characteristically the closest dry-land to the shell beds where the shellfish are harvested (eg Mannino and Thomas 2001). This is mirrored in the archaeological record by the location of the majority of shell middens along palaeocoastlines adjacent to the palaeo-shell beds (eg Van der Schriek *et al.* 2007a, 2007b, 2008). However, archaeological evidence suggests that (whole) shellfish may be carried up to 5-10km from the coastline in some circumstances (eg Bailey and Craighead 2003). Whilst this is likely to be of a more restricted nature, this phenomenon can also be detected in late-Pleistocene and Holocene sites, where the quantity (and species) of shellfish changes through the deposit mirroring the changes in distance to the coastline due to sea level change (see Bailey and Flemming 2008). It has also been shown that shellfish are often

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processed by removing the flesh from the shell (defleshing) at sites adjacent to the shell beds, before the meat is carried elsewhere (eg Meehan 1977, Bird and Bliege Bird 1997; Bird *et al.* 2002; Mannino and Thomas 2002), making detection at the place of consumption very difficult.

Analysis of the Danish Ertebølle sites has shown that this culture established generalist camps on the coastline forming the famous shell middens (Raemaekers 1997). These were used to access both coastal and terrestrial resources, not just shellfish, and this is reflected in the deposits. A distribution analysis of sites showed that there were very few inland sites within a 5km band of the coastline. This suggests that they used their coastal bases to exploit a territory up to 5km inland. The inland camps were found to be specialist terrestrial camps, exploiting predominantly terrestrial resources. It therefore seems likely that the Ertebølle coastal sites were used for both processing and consumption of shellfish, as well as other coastal resources. The Japanese sites of the Jomon period also demonstrate a range of activities from shellfish processing to storage pits (eg Habu 2004).

Shell midden accumulation is not only linked to subsistence; feasting activities can also play a role in formation. Feasting activity is strongly linked to ritual behaviour, whether as part of annual events or more irregular activities. Annual large scale feasting has been documented by ethnographer Betty Meehan (1977, 1982, 1983), who followed the Anbarra of Arnhem Land, Australia. These feasts included events such as the Kunapipi coming of age ceremony. The Anbarra carry out *Tapes hiantina* collection using a wooden stick for extraction from the mud and a bag woven of tree fibres to carry them. Meehan estimated that in two hours the average woman could gather 11.5kg of live weight in shells. The volume of shells gathered through the season amounted to 8m³, with a live weight of 7300kg (or 244,000 molluscs) (Meehan 1982).

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However shellfish was not eaten exclusively unless the situation required, and other sources of food would also be utilised (see also Collier 1987). Indeed Meehan goes on to list other sources of nutrition: carbohydrates at 0.5 kg, gathered vegetables 0.4 kg, and gathered or hunted flesh a net of 0.6 kg per day. This was estimated to be equivalent to 2400 kilocalories per head per day (Meehan 1977). This evidence fits in with other studies suggesting that protein alone is not a sustainable diet, and can in extreme circumstances result in death (eg Noli and Avery 1988).

Estimates for the amount of meat from a shellfish vary from 6-7% for mussel (Roberts and McKenzie 1983) to 12% for *Strombus gigas* (Berg 1976); however *Tapes hiantina* yields up to 15-20% (Meehan 1977). Meehan also observed that *Tapes* was specifically targeted, with other edible and accessible shellfish playing a lesser role.

A large number of studies have found that shellfish exploitation has been seasonal at the sites in question. This conclusion has been reached via either isotope analysis or thin section analysis of shells from the sites. Oxygen isotope analysis has developed a lot since Shackleton's 1967 study (Shackleton 1967), and is now a tried and tested method (eg Culleton *et al.* 2009). However the thin section technique is still an important alternative to this technique, using variation in shell growth rate to infer seasonality (eg Milner 2001).

Seasonality has proved to be an important strategy, especially in regions where many food sources are only seasonally available. For example on Kodiak Island in Alaska clams were found to have been exploited during autumn, winter and spring but not in summer when the salmon run takes place and salmon were widely available (Fitzhugh 1995). Reinforcing this seasonal cycle toxic shellfish poisoning combined with toxic "red tide" algal blooms are more prevalent during summer months.

The Anbarra were observed to resort to shellfish during "lean times", with shellfish never accounting for more than 10% of their diet (Meehan 1977;

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1982). This suggests that the shell in the shell middens created by these people only represented a small proportion of their diet, with other sources underrepresented in the midden. Seasonality has also been inferred in a number of archaeological sites such as Oronsay (Mellars and Wilkinson 1980; Richards and Mellars 1998) and Culverwell (Thomas and Mannino 1999; Mannino and Thomas 2001).

In other areas, shell middens have accumulated as a part of funerary practices. Perhaps the best evidence for this comes from the Brazilian Sambaquis; these are huge shell mounds, some of which are in excess of 50m high. They appear to have formed as a result of both occupation and funerary activity (Gaspar 1998; Barbosa *et al.* 2004; Villagran and Deblasis 2008; Gaspar *et al.* 2008; Wagner *et al.* 2011). Occupation of the sites is thought to have been broadly continuous, punctuated only by periods when sea level was not optimal for their location. The range of material within the deposits suggests small communities of perhaps twenty people exploiting the coastal margin. However some sites were found to be lacking in occupation material and structures, but did contain many burials. This perhaps indicates that some sites were dedicated to funerary practices and burial and developed purely as a result of this activity (Gaspar 1998).

The Californian shell mounds of San Francisco Bay are another excellent example of sites which were perhaps dedicated to burial (Luby and Gruber 1999). These sites are packed with burials and careful excavation of these revealed that the burials took place first, and were followed by feasting which resulted in the deposition of the shells. The basal layers of the excavated sites showed the grave cuts had been excavated into the land surface, before shells had been deposited on top of the graves, sealing them in. Evidence of occupation in these sites was absent. Similar mortuary sites exist in modern Senegal in the Saloum Delta, where large mounds have formed islands of shell within the delta. Some are former settlement sites, abandoned and reused as cemeteries. The local custom is for oyster shells to be deposited on the graves, ensuring

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the growth of the shell mound (Camara in press).

In contrast to this, the sites of Tévéc and Hoëdic in Brittany feature a number of burials within shell midden material. However, the shell middens themselves seem to represent deposition as a result of occupation rather than specific burial ceremonies. The assemblages suggest a reliance on coastal resources with a high dependence on marine resources. Evidence for seasonality indicates that resources were exploited year round, which would suggest that either the site was visited on a regular basis throughout the year, or that it was the focus of a more sedentary community, perhaps used as a home base from which to forage (Dupont *et al.* 2009). The graves are elaborate, some with red deer antler arranged around the edge of the grave cuts. Human remains have also been found in a large number of Ertebølle sites, with finger and toe bones being amongst the numerous finds (Raemaekers 1997). The North West Coast of America shows a similar tendency for burial within shell middens, often immediately behind the house of the deceased (Suttles 1991). The Muge shell mounds of Portugal have been shown to have a high numbers of burials within them, again showing a relationship between shellfish sites and death (Bicho *et al.* 2010). The trend therefore seems to be for burial within the shell midden, in the immediate vicinity of occupation. The notable exception to this are the specialised sites dedicated to funerary practice of the Sambaquis, Californian, and Saloum Delta sites.

The size and shape of shell middens can be extremely variable, as highlighted by the description of sites above. This can be related to the activities being carried out at the site, and the length and frequency of occupation (eg Claassen 1998; Erlandson and Moss 2001). It is also related to the intensity with which resources are being exploited. A key indicator for intensive exploitation can be a decrease in size of shells for specific species through time within the deposit. Other lines of evidence also need to be considered, since environmental factors can also impact upon the size of shellfish (eg Faulkner 2010; Mannino and Thomas, 2001,

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2002; Milner *et al.* 2007). As described earlier, Holocene coastlines have been far from stable, and subtle changes over thousands of years have slowly changed many environments, which in turn has impacted upon the composition and productivity of the shell beds. This not only affects the recruitment levels and juvenile survivorship of the shellfish, but can also impact upon the maximum physical size a shellfish can reach. Such analysis has been undertaken for sites in Australia (Darwin and Weipa), showing continuous exploitation (eg Broom 1985; Bailey 1993; Bourke 2000; 2003). Another study focusing on the Blue Mud Bay shell middens has demonstrated a variation in the intensity of exploitation of *Anadara granosa*. The fact that this shellfish reproduces and grows rapidly means it is ideally suited for these measurements (Faulkner 2010). The findings suggest that there were two periods of intense exploitation, broken up by a period of less intense exploitation when accumulation rates were slower and shellfish size increased. As the example above demonstrates, the intensity of exploitation can vary through time. The size of sites has also been found to be informative on the timings and intensity of exploitation.

Findings from the Weipa group of shell mounds suggest that the smaller sites are of greater antiquity, and that the larger are much younger, and accumulated rapidly (Bailey 1993; Bailey *et al.* 1994). This would suggest an intensification of resource exploitation over time, culminating in the accumulation of the larger shell mounds. In other areas of the world this has also been shown to be the case, for example the Ten Thousand Islands Shell Works (so called “works” because of their similarity to earth works) of Florida have been shown to originate from smaller shell rings (Russo and Heide 2003). The shell rings pre-date the later shell works, with many rings being abandoned. Those that were not were buried beneath the later shell works. The shell works became population centres within the mangroves, replacing the smaller sites (Schwadron 2010a, 2010b).

As demonstrated in the examples above, the internal structure of a shell mound can inform on the processes and rates of formation. These are

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key to understanding exploitation behaviour and changes in this behaviour over time. The primary way to observe and understand these structures is by excavation.

Excavating shell middens is notoriously labour intensive; however it has been undertaken at a number of sites, in some cases with spectacular results (eg Vila *et al.* 2007; Briz *et al.* 2011). Over twenty years of excavation on Tierra del Fuegan shell middens have resulted in the reconstruction of site structure and evolution. The use of microstratigraphic analysis has enabled the detection of up to twenty discrete seasonal deposits in shell middens (eg Villagran *et al.* 2011).

In Florida the excavation of the Sewee shell ring has enabled a reconstruction of the internal structure of the shell ring, and reconstruction of growth of the site (Figure 2). The authors were also able to conclude that it was once a complete ring, as it has since been broken (Russo and Heide 2003). These studies show the value of excavation despite the obvious costs; but they also highlight how little is known about the processes of formation in shell mounds. The potential of these methods is clear and can offer further insight into shell mound building and associated activities.

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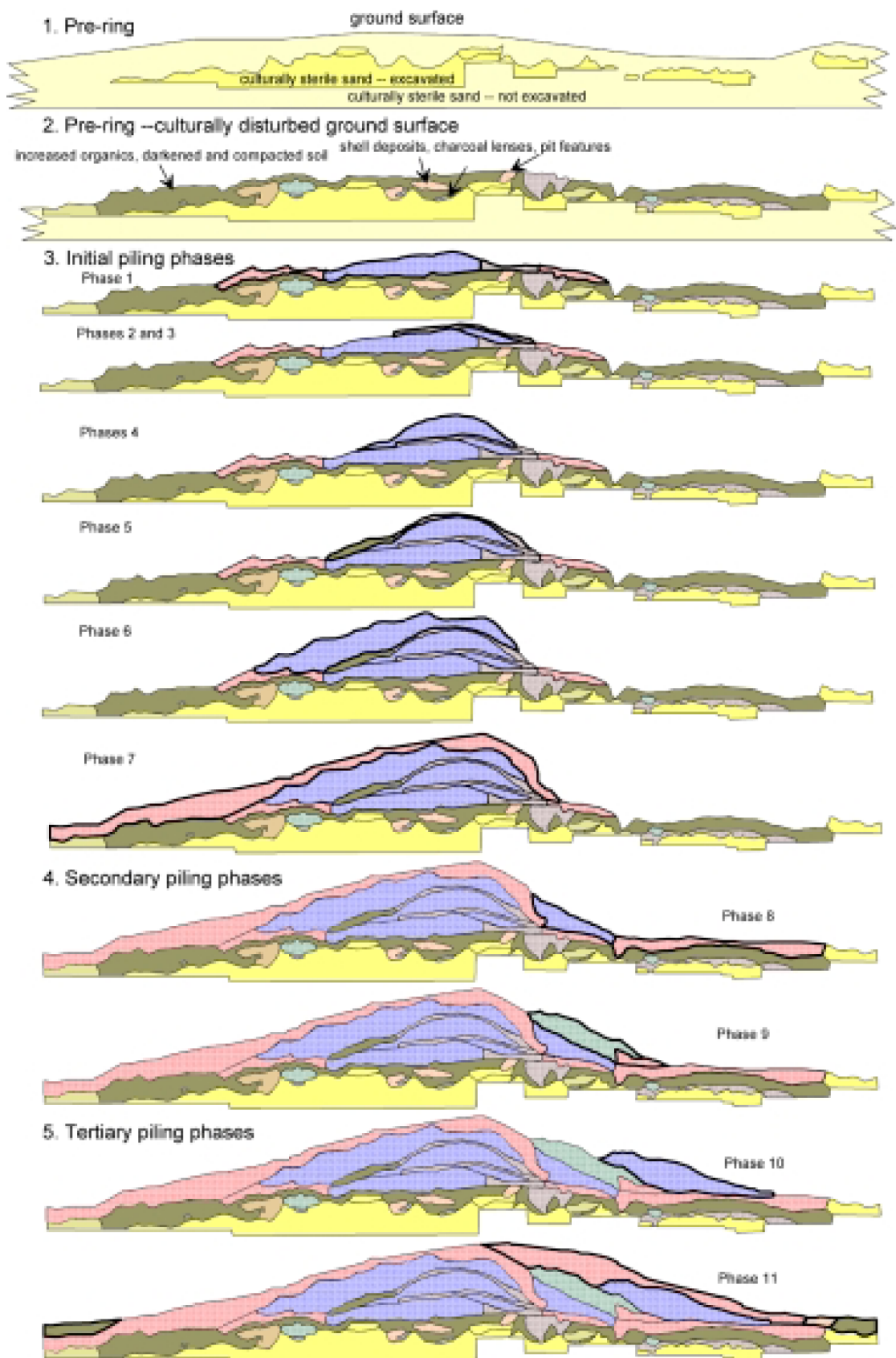


Figure 2: Evolution of the Sewee Shell Ring (Russo and Heide 2003)

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Closely related to these questions is the emergence of large shell mounds. This returns to the theme of whether prehistoric shellfish exploitation has been constant, or whether there was an intensification through the mid-Holocene. Large shell mounds should be well positioned to answer this; however different sites have revealed different answers. The shell mounds of Australian and Florida suggest intensification through the Holocene (eg Bailey 1994; Schwadron 2010a, 2010b); in contrast Scottish sites suggest a constant rate of exploitation (eg Mellars and Wilkinson 1980).

Pursuing this goal, the research of Russo and Heide (2003) can be applied (Figure 2), for which they have created a model for the evolution of the site (Figure 3). Briefly they suggest that initial deposition is vertical, followed by horizontal deposition of “feast” shellfish and capping by domestic material. Therefore the height of the shellmound is predominantly gained during the initial stages of deposition, with only limited subsequent vertical growth.

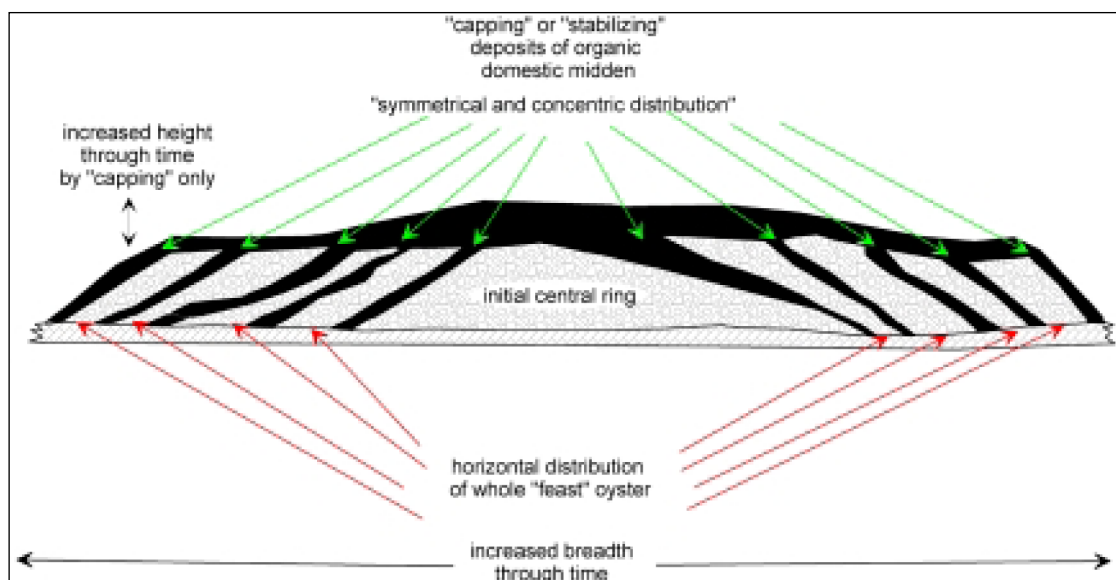


Figure 3: Vertical accumulation model for the Sewee Ring Mound (Russo and Heide 2003)

There are three models for the evolution of large shell mounds. These are primarily based on the observations of a single large shell mound dominating a group of smaller sites. Although the Sewee Shell Ring is not

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part of a larger group it still conforms to the first model:

- That large shell mounds emerge as a result of intensification at a single site, and therefore have a single point of origin
- Larger shell mounds are an amalgamation of smaller sites, therefore have multiple points of origin
- Shell mounds of different sizes have different functions, therefore different structures

For the Sewee shell ring mound Russo and Heide (2003) proposed the following model that it originates from a single point, compatible with a stable and continuous exploitation of shellfish. In cases where these develop into larger shell works, the shell ring is the point of origin, showing an intensification over time (Figure 4). However what this study lacked is a high resolution dating program of the sites to determine the rates of formation of the site.

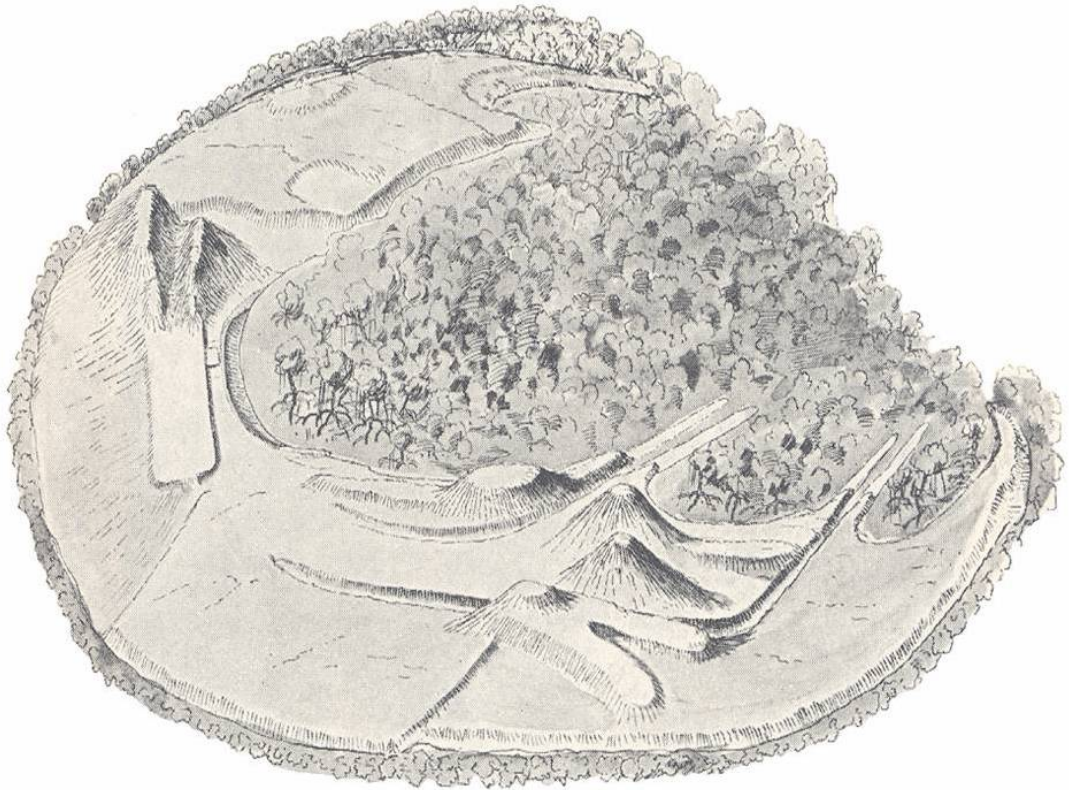


Figure 4: Sketch of a shell works (Anon. nd.)

Comparatively little work has been undertaken to address the modes of evolution of shell mounds by analysing the processes of mound formation. Yet the emergence of large shell mounds is one of the defining characteristic of Holocene shell midden assemblages and is pivotal to understanding the question of intensification versus constant long term exploitation. A key reason for the lack of research is the costs involved in undertaking this kind of investigation. Nevertheless this remains a key objective for shell midden studies: to determine the reasons for and modes of emergence of large shell mounds and to ascertain whether they represent an intensification of activity, or prolonged continuous exploitation at the same location.

1.3 Chapter summary

This section has shown that human exploitation of aquatic environments and specifically shellfish has its roots in the distant past. This activity appears to have greatly intensified during the mid-Holocene, however

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there are a number of key factors which could affect this interpretation, including climate and sea level change, and coastal stability. A number of studies have been initiated to investigate Holocene shell middens to determine the intensity and longevity of their use. A key question is whether large shell sites are the result of short bursts of intensive use (intensification), or whether they have built up more slowly as part of a constant rate of exploitation due to increased stability along a stretch of shoreline. These questions are highly relevant to this study, and therefore form part of the research questions.

The evidence reviewed here shows that contrary to the earliest (Palaeolithic) evidence, intensive shellfish gathering was taking place before 6000BP, but that it was focused on the immediate foreshore, which is in all but a handful of cases now submerged. Added to this the dynamic nature of the coastlines (in response to sea level change) and it becomes apparent that unless exceptional (stabilising) circumstances occur, the constant change would not allow for large deposits to accumulate. Shellfish are seldom carried far, meaning that evidence is now submerged, and unlikely to have reached the size of mid-Holocene sites.

To conclude this section, it has been shown that the timing and distribution of shell mound formation is critical in our understanding of coastal resource exploitation. Intrinsicly linked into this is the question of intensification and the emergence of large shell mounds. Simply to excavate a large mound is not enough; a robust dating program is also necessary in order to determine the rates of formation and intensity of exploitation. Finally it is imperative to investigate social and economic processes behind site formation, and determine any responses to climate and sea level change.

Chapter 2

Archaeological Background

2. Archaeological Background

2.1 Introduction

The introduction chapter has already highlighted the significance and potential of the Southern Red Sea, due both to low density of previous studies, and the position of the region as a contact point between Arabia and Africa. The notable exception is in Oman, where continuing studies highlight the excellent preservation and high density of prehistoric coastal sites. In the Southern Red Sea such sites offer the possibility of answering some of the key questions highlighted in the introduction. Existing evidence of shell middens and tectonic instability should allow an in depth assessment of the processes and rates of formation of shell middens in the region, social and economic responses to environmental change (both through climatic and tectonic instability) and more broadly an assessment of whether shellfish exploitation in the region intensified through the Holocene. This chapter will review the coastal archaeology of the Arabian Peninsula and Farasan Islands (see Figure 5), providing a context for the work within this thesis.

2.2 The Arabian Peninsula

A Palaeolithic presence on the Arabian Peninsula has already been briefly reviewed. It is likely that this population was not limited to the interior (eg Henshilwood *et al.* 2001; Petraglia 2003; Petraglia and AlSharekh 2003; AlSharekh and Arabia 2006; Rose 2007; Petraglia and Rose 2009; Rose and Usik 2009; Armitage *et al.* 2011), especially if the coastal oasis theory (Faure *et al.* 2002) is correct (eg Walter *et al.* 2000; Stringer 2000; Erlandson 2001; Flemming *et al.* 2003; Bailey 2004; 2007a). Indeed the Middle Stone Age site of Abdur on the Eritrean Red Sea coast was thought to contain the earliest evidence of coastal resource exploitation in the Red Sea relating to MIS5e (Walter *et al.* 2000). However this has proved controversial and has been reinterpreted as a natural death assemblage of shells (Bruggemann *et al.* 2004).

Holocene coastal populations around the Arabian Peninsula could have been descendants of this earlier Palaeolithic population. The degree to which exchange of ideas and genes across the Red Sea took place is a matter of debate, but it seems likely to have played a key role, particularly in the arrival of some of the Neolithic farming package. This includes the “red stick burnished ware” typical of the Gash Delta in Sudan which appeared around 4000BP (Tosi 1986; Edens and Wilkinson 1998). However pastoralism was already established on the peninsula by a population that was largely aceramic. Evidence for domesticated herd animals dates back to the ninth millennium BP at sites such as WTH (eg Uerpmann *et al.* 2000; Uerpmann and Uerpmann 2008; Uerpmann *et al.* 2009; McCorriston and Martin 2009). The origin of these domesticates is likely to be either the Levant or Africa, although the debate remains open (eg Uerpmann 1996; Uerpmann *et al.* 2009).

The exploitation of coastal resources on the Arabian Peninsula during the mid-Holocene has been explored in a number of key papers (eg Beech 2004; Durrani 2005; Biagi 2006; Méry *et al.* 2008). These have tended to focus on specific areas within the region; here the evidence from the entire Peninsula and adjacent coastlines is reviewed in order to construct a regional model of shellfish exploitation for the mid-Holocene. However, only sites which have been successfully dated using absolute dating techniques have been included in order to avoid ambiguity. These sites are listed in Table 1 and their locations shown in Figure 5.

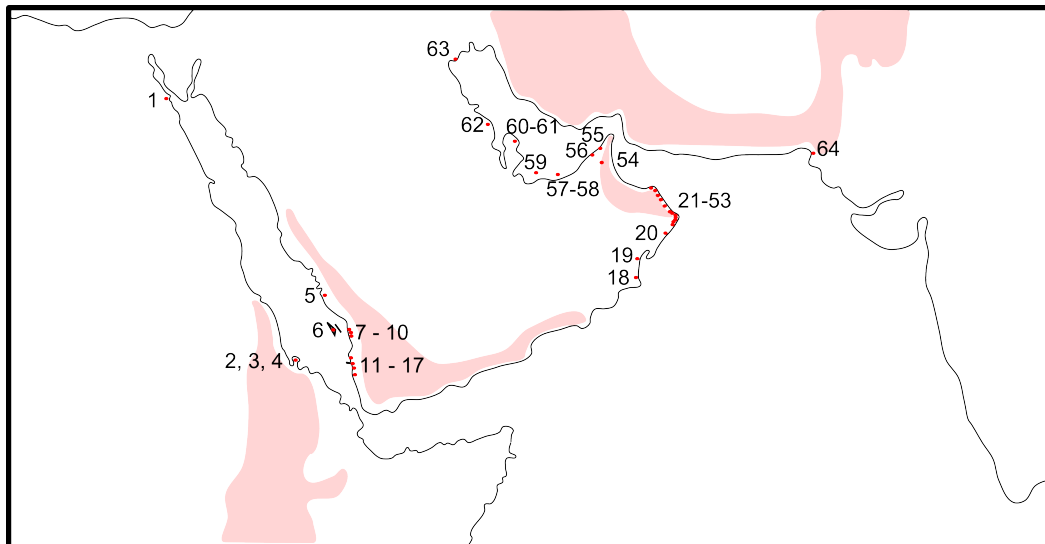


Figure 5: Location of dated shell midden sites on the Arabian Peninsula and adjacent coastlines. Mountainous areas are shaded red.

2. Archaeological Background

No. on Map	Region	Site Code	Reference	Lab No.	Uncal BP	Error	Distance from sea (km)	ASL (m)	Primary Species	Habitat (Substrate)	Size (m)	Depth (m)	Site Attributes
1	Egypt	El Gouna	Vermeesch et al. 2005	GA-23726	5800	40	5	20	<i>Terebralia palustris</i>	Mangrove Mud	10	1.5	O
2	Eritrea	Asfet	Mayer and Beyin 2009	A0794	5385	15	0.8	30	<i>Terebralia palustris</i>	Mangrove Mud		0.25	
3	Eritrea	Gelalo Northwest	Mayer and Beyin 2009	GX-32910	7900	190	4		<i>Terebralia palustris</i>	Mangrove Mud		0.25	
4	Eritrea	Misse East	Mayer and Beyin 2009	GX-32911	7330	190	15		<i>Atactodea glabrata</i>	Intertidal Sand		0.25	
5	Saudi Arabia	al-Birk	Bailey et al. 2007a	BETA-191459	5560	70							
6	Saudi Arabia	Farasan	Zarins and Al-Badr 1986	GX-10354	5335	225							
7	Saudi Arabia	217-175	Zarins and Al-Badr 1986	GX-10340	5360	180			<i>Turbo</i> sp.	Rocky			E, H
8	Saudi Arabia	217-174	Zarins and Al-Badr 1986	GX-10341	5470	175							
9	Saudi Arabia	217-181	Grigson et al. 1989	GX-11210	4885	115							
10	Saudi Arabia	217-182	Grigson et al. 1989	GX-11209	6150	130							
11	Yemen	ASH	Tosi 1986	GX-13781	7770	95							
12	Yemen	IBN-4	Tosi 1986	Beta-23577	5720	70							
13	Yemen	JHB	Tosi 1986	Beta-23582	7500	80	5	15	<i>Terebralia palustris</i>	Mangrove Mud			L, D, P
14	Yemen	QMM-3	Tosi 1986	Beta-23578	5730	90			<i>Terebralia palustris</i>	Mangrove Mud	45x30		P
15	Yemen	QMM-4	Tosi 1986	Beta-23580	5080	80			<i>Terebralia palustris</i>	Mangrove Mud	220x200	deflated	
16	Yemen	SRD-1	Tosi 1986	Beta-23580	5100	90	10		<i>Terebralia palustris</i>	Mangrove Mud			H, D, F
17	Yemen	SRD-1N	Tosi 1986	GX-13782	6325	90	10		<i>Terebralia palustris</i>	Mangrove Mud			H, D, F
18	Oman	SHW-1	Biagi 1988	Bln-3644/II	6220	60			<i>Marcia ceylonensis</i>	Mangrove Mud			
19	Oman	SRB-1	Biagi 1988	Bln-3702/III	4859	70			<i>Marcia ceylonensis</i>	Mangrove Mud			
20	Oman	SAQ-1	Biagi 1994	Bln-3459/I	6040	60			<i>Bullia mauritania</i>	Mangrove Mud			L
21	Oman	KHB-1	Biagi 1988		5120	80		35	<i>Marcia ceylonensis</i> , Fish	Mangrove Mud			S, P, V
22	Oman	DFH-2	Biagi 1988	Bln-3643/III	5400	60			<i>Terebralia palustris</i>	Mangrove Mud			
23	Oman	RJ-2	Cleuziou & Tosi 1990	Beta-25906	4600	70							
24	Oman	HD-1	Glover et al. 1990; Reade 1990	UCL-122	5600	500							C
25	Oman	HD-2	Glover et al. 1990; Reade 1990	UCL-125	6100	300							
26	Oman	KJ-12	Biagi 1988	Bln-3615/II	4740	60			<i>Anadara uropigmelana</i>	Sandy			
27	Oman	SH-3	Biagi 1988	Bln-3650/1	4160	60			<i>Anadara uropigmelana</i>	Sandy			
28	Oman	SH-4e	Biagi 1988	Bln-3645/1	6050	70			<i>Anadara uropigmelana</i>	Sandy			
29	Oman	BB-1	Uerpmann 1992	Hv-10921	5850	115							

2. Archaeological Background

No. on Map	Region	Site Code	Reference	Lab No.	Uncal BP	Error	Distance from sea (km)	ASL (m)	Primary Species	Habitat (Substrate)	Size (m)	Depth (m)	Site Attributes
29	Oman	BB-1	Uerpmann 1992	Hv-10921	5850	115							
30	Oman	GAS-1	Biagi 1994	GX-17881	5127	80							
31	Oman	DB-1	Biagi 1988	Bln-5270/II	5420	60			<i>Anadara uropigimelana</i>	Sandy			
32	Oman	BK	Uerpmann 1992	Hv-10924	6610	105			<i>Terebralia palustris</i>	Mangrove Mud			
33	Oman	BK-11	Biagi 1988	Bln-3648/III	5870	60			<i>Anadara uropigimelana</i>	Lagoon/Mudflats			
34	Oman	BK-3	Biagi 1988	Bln-3388/1	5210	60			<i>Anadara uropigimelana</i>	Lagoon/Mudflats			
35	Oman	BK-5	Biagi 1988	Bln-3389/III	5700	60			<i>Anadara uropigimelana</i>	Lagoon/Mudflats			
36	Oman	BK-7	Biagi 1988	Bln-3390/1	5200	70			<i>Anadara uropigimelana</i>	Lagoon/Mudflats			
37	Oman	RH-1	Uerpmann 1992	Hv-12977	4755	105							
38	Oman	RH-10	Biagi et al. 1984	Hv-10001	6910	105			<i>Terebralia palustris</i>	Mangrove Mud			R
39	Oman	RH-12	Uerpmann 1992	Hv-13743	5960	100							
40	Oman	RH-3	Biagi et al. 1984	P-2738	4170	220							
41	Oman	RH-4	Biagi 1994	P-2739	5140	200							
42	Oman	RH-5	Biagi 1994	Bln-3396	6080	60							F
43	Oman	RH-6	Uerpmann and Uerpmann 1996	Bln-3637/III	6530	80			<i>Terebralia palustris, Anadara sp.</i>	Marine/Mangrove species		1.7	S, R, H, D, F, B
44	Oman	RH-7	Durante and Tosi 1977	Hv-10926	7065	105				Mangrove Mud			L
45	Oman	Qurm N	Uerpmann 1992	Hv-14212	5880	160			<i>Terebralia palustris</i>	Mangrove Mud			
46	Oman	WW	Uerpmann 1989	Hv-12968	7050	150	3		<i>Terebralia palustris</i>	Mangrove Mud			
47	Oman	SWY-11	Charpentier et al. 2000	Pa-1716	7275	60				Marine/Mangrove species			S, L, F
48	Oman	Saruq	Uerpmann 1992	Hv-14211	6885	105			<i>Terebralia palustris</i>	Mangrove Mud			
49	Oman	Daghmar	Uerpmann 1992	Hv-10922	6545	105							
50	Oman	DG	Uerpmann 1992	Hv-10922	6545	105			<i>Terebralia palustris, Anadara uropigimelana</i>	Mangrove Mud			
51	Oman	DG-1	Biagi 1988	Bln-3392/1	4970	50							
52	Oman	KM-1	Phillips and Wilkinson 1979	ANU-2813	5130	90							
53	Oman	BJ-1	Uerpmann 1992	Hv-12975	5730	105			<i>Anadara sp.</i>	Sandy/Lagoon/Mudflats			
54	UAE	BHS-18	Kiesewetter et al. 2000	na	7100	50							S, H, D
55	UAE	RA-6	Biagi 2006	Bln-4735	6181	50			<i>Terebralia palustris</i>	Mangrove Mud			R, L, F, U, C, E
56	UAE	Akab	Mery et al. 2009	Pa-2355									S, P, H, D, F

No. on Map	Region	Site Code	Reference	Lab No.	Uncal BP	Error	Distance from sea (km)	ASL (m)	Primary Species	Habitat (Substrate)	Size (m)	Depth (m)	Site Attributes
57	UAE	MR1	Beech 2004	HD-20756	7036	30	0		<i>Asaphis violascens</i> / <i>Hexaplex kuesterianus</i>	Sandy/Rocky			S, R, H, D, F, C
58	UAE	MR11	Beech et al. 2005	SUERC-3612	6750	40	0		<i>Asaphis violascens</i> / <i>Lunella coronata</i>	Sandy/Rocky			A, H, D, F, C
59	UAE	DA11	Flavin and Shepherd 1994	AA-52544	6395	60	0		<i>Pinctada</i> / <i>Lunella</i> / <i>Circenita</i>	Rocky			S, P, H, D, F, C, B
60	Qatar	Khor D	Inizan 1979	Unpubl1	6560	120							U
61	Qatar	Khor FB	Inizan 1979	mc-2021	6420	100				Maine/Mangrove species			L, F, U
62	Saudi Arabia	Dosariyah	Burkholder 1972	GX-2818	6900	330			Oyster	Rocky		3.5	P, H, D, F, C, E
63	Kuwait	H-3	Carter and Crawford 2003	GU-9310	6480	45			<i>Lunella</i>	Rocky marine			S, A, H, D, F, C, B
64	Pakistan	Daun-1	Biagi 2006	GN-26328	6380	40			<i>Terebralia palustris</i> and <i>Ostreidae</i>	Mangrove Mud	25	0.25	C

Table 1: Shell mounds of the Arabian Peninsula and adjacent coastlines and information on each site. Site Attribute codes: E Ostrich Egg Shell, H Hunted Animal Bones, D Domesticated Animal Bones, L Arabian Bifacial Tradition, C Ceramics (Local), U Pottery (Ubaid), V Stone Vessel, R Evidence for Structure, P Structure (Plaster), A Structure (Block), F Fish Bones, S Shellfish Hook, B Evidence for Boats.

A number of countries have commissioned survey projects to map the archaeological sites within their territories; these have been responsible for locating a number of coastal sites, some of which have subsequently been investigated (eg Zarins *et al.* 1981; Zarins and Al-Badr 1986; Zarins and Zahrani 1985; Tosi 1985; Tosi 1986).

The oldest evidence for shellfish exploitation in this region is the eighth millennium BP sites of Misse and Gelalo in Eritrea (Mayer and Beyin 2009), and ASH and JHB in Yemen (Tosi 1986). These pre-date modern sea levels by 2000 years, a time when sea level would have been 20m lower (Siddall *et al.* 2004); they must therefore either have accumulated above modern sea level preventing inundation, or have been subject to tectonic forcing. The Eritrean sites are both situated inland on hilltops, at 4km and 15km from the present shoreline (for Gelalo and Misse respectively). The distance to shore when they were accumulating is uncertain, since active tectonics in the region has strongly influenced the coastlines, but they both would have been inland.

The Gelalo site is dominated by the gastropod *Terebralia palustris*, a mangrove dwelling species. This species is easy to harvest, and abundant in mangroves; it is a dominant and recurring feature of the majority of coastal sites in the region regardless of age. The Misse site was dominated by *Atactodea glabrata*, an intertidal sand dwelling species. The difference in species perhaps represents the closest shellfish habitat to each site. The authors speculate that these sites were occupied as part of a transhumance seasonal migration with livestock (Mayer and Beyin 2009). Ostrich eggshell beads were also found at the site, although it is unclear whether they were manufactured at the site, or brought in. It is suggested that the presence of marine shell at the fifth millennium BP inland site of Lake Baska in the Afar region supports a coastal link (Mayer and Beyin 2009), but without further investigation it is inconclusive since they could have arrived there through other agencies such as trade networks.

On the Yemeni Tihama Plain are two more sites predating 6000BP. Less is known about the site of ASH, but it is thought to represent a eighth millennium

BP hunter-gatherer camp used to exploit both terrestrial herd animals (likely cattle and equids) as well as locally abundant shellfish. The seventh millennium BP site of JHB is close to the coast, and also contains the bones of wild herd animals, such as equids and cattle with shellfish. However the bones were surface finds and Bronze Age pottery was also found on the surface, adding complexity to the interpretation of the site. Both sites are palimpsests, potentially reoccupied many times after the initial shell midden accumulated, creating complicated stratigraphies (Durrani 2005). A single obsidian tanged bifacial arrowhead at JHB is considered similar in typology to contemporaries in the Rub Al-Khali, representing a tentative link to inland populations. This site is 5km from the modern shoreline and currently 15m ASL (Tosi 1985). This together with the early date (predating the stabilisation of sea levels) suggests tectonic and/or hydro-isostatic movement of the land-surface.

In close proximity to these sites on the Yemeni Tihama Plain, are the sites of IBN-4, SRD-1, QMM-3 and QMM-4 (Tosi 1986). These sites are all mangrove sites composed primarily of *Terebralia sp.*, and dating between the sixth and seventh millennia BP. With the exceptions of the two excavated sites of JHB and SRD, little is known about the sites in this area, as they were discovered during a survey and only minimal information was recorded on their location and surface composition. However their presence and the fact that they are similar to the sites further around the coast in Oman suggest a continuity of exploitation strategies and site type. Whether any of these sites will demonstrate a direct use of animal husbandry and seasonal movements is yet to be explored. No shellfish hooks were recovered from the Yemeni sites, however finds resembling net weights were found and fish bones were present in the deposits.

The site of SRD is slightly later in date at 6325 ± 90 BP (Tosi 1986); domestic cattle bones have been found, with some wild equid and ass. An abundance of fish bones at the site is telling, although no fishhooks or net weights were recovered. As with JHB, this site is part of a complex palimpsest of multiphase activity, making associations between finds such as domesticated animal

bones and the shell middens on which they sit difficult, but in this case the associations are determined to be contemporaneous.

What is certain from these sites is that there was a population exploiting coastal resources in the eighth to fourth millennium BP at least. Additional evidence for trade networks or population mobility comes from the presence of obsidian lithics at all of the shell midden sites recorded in this area.

Slightly further along the Tihama Plain and into Saudi Arabia another group of sixth millennium BP shell middens have been found in the Jizan area: 217-182, al-Birk, 217-179, 217-175, and 217-181. These have proved to be aceramic in nature, and have limited quantities of bone which have proved unidentifiable. An abundance of lithics, including bifacial technology suggests wider contacts. Grind stones, fire-cracked stones, hearths, ostrich eggshell and notched net weights were also found, but no shellfish hooks (Zarins and Al-Badr 1986). Many of these sites are up to 10km from the present coastline, with evidence for palaeoshorelines suggesting that they accumulated at the shore. Sites were also discovered on the Farasan islands, c.40km from the mainland, dating to the later sixth millennium BP (Zarins and Al-Badr 1986).

On the opposite coastline the c.5000BP Eritrean site of Asfet, in the same region as the earlier sites of Gelalo and Misse, is another mangrove specific site composed predominantly of *Terebralia sp.* No evidence of any other activities was found at the site, with the exception of lithic manufacture. The shallow nature of the deposit (c.25cm) is likely to be responsible for the absence of faunal remains, if they were there in the first place (Mayer and Beyin 2009).

Further north on the same side of the Red Sea the c.5800BP Egyptian site of El Gouna is another *Terebralia sp.* dominated site, which is a member of a small group of shell mounds. The site is composed of a number of occupation layers, each separated by sterile aeolian sands. Amongst the finds were abundant lithics, small fragments of ostrich eggshell, and fragments of ochre. The sterile layers suggest at the very least seasonal abandonment; given the

depth of the sterile layers the periods of abandonment may even be longer, perhaps due to changing environmental or ecological conditions. The site is now nearly 5km inland and c.20m ASL, but was thought to have been on the shoreline of a mangrove during accumulation. Interestingly the authors' state that based on the typology of the lithics at the site, El-Gouna cannot be associated with any other known site in the Red Sea area, but that the typology is similar to that of the Nile Valley (Vermeersch *et al.* 2005a). This might suggest seasonal movements between the fertile Nile Valley and the productive coastal plains, possibly in association with the seasonal flooding of the Nile, when resources in the basin may have been less accessible. Given the large sterile layers within the middens, it could also be a response to catastrophic flooding, or flood failure in the Nile, leading to reduced resource availability and necessitating a move to more reliable resources. Finally it must also be considered that the link in stone tool technology could be a relict of an earlier movement, with coastal communities being independent of the Nile Valley.

Other sites on this coastline include the oyster mounds of Denkalalo in Djibouti (Poisblaud 2002) and the estuarine mussel sites of Nogal and Obbia in Somalia (Clark 1954). Although these sites are thought to date to the same period, none have been conclusively dated and therefore cannot be included in this review.

Shell middens appear along the coastlines of the Gulf side of the Arabian Peninsula at broadly the same time as in the Red Sea. Many of these sites are strongly associated with fishing, demonstrated by the assemblages of fish hooks, lures and net weights at many sites. There is a key concentration of sites along the UAE and Omani coastlines, with sites stretching along the southern coast of the Gulf as far as Kuwait. The majority of these sites are dominated by *Terebralia palustris*.

There are a disproportionately large number of both known and dated shell midden sites in Oman (Figure 5). This may be due to a greater focus and intensity of survey and investigative work, but this will only be quantified with

further research. Certainly it has been claimed that there are an exceptional number of fifth millennium BP shell middens along the Oman Peninsula (Biagi and Nisbet 2006), however very few of these have been studied in detail. The fact that no sites have been published on the stretch of coastline south of SHW-1 all the way to the southern tip of Yemen suggests that it is likely to be a gap in our knowledge rather than an absence of sites. Indeed oil workers along this section of Yemeni coastline report the presence of tel-like mounds along the coastline, many of which are potential shell mounds (pers. com. 2007).

The vast majority of the sites in the region cluster between 8000-4000BP, and are commonly composed of either *Terebralia palustris* or *Anadara uropigimelana*. Many of these sites show strong adaptations to fishing as well as shellfish gathering. Indeed sites such as KHB-1 are specialised fishing settlements. Fishing equipment such as fish hooks manufactured from shell, net weights, and fish gorges have been found at most sites. At KHB-1 the *chaîne opératoire* of fish hook production has been determined by the examination both of tools and unfinished fish hooks (Cavulli *et al.* 2009). Pelagic fishing has been suggested at sites such as RA-6, RH-6, Wadi Shab, and Khor Milkh implying the use of boats (eg Wilkens 2005; Méry *et al.* 2008). However pelagic fish are often available close to shore at certain times of the year in many locations, therefore the possibility that these were caught without the need to leave the shore must also be considered. Environmental and climate change may also have influenced the availability and behaviour of these fish.

It is thought that these sites may have been seasonally sedentary through autumn and winter and perhaps even summer as well (Biagi and Nisbet 2006). These would have formed part of a broader exploitation strategy taking advantage of a number of resources. Many of the shell midden sites have evidence for structures, usually in the form of post holes, defining curvilinear features. This indicates that the sites were settled long enough for structures to be erected; the foundations of some have been found excavated into the bedrock. Cemeteries at a number of sites (such as RA-6) also

suggest a more sedentary lifestyle, or at least more permanent places in the landscape. The cemetery at RH-5 shows a level of symbolism in exception to anything yet found from this era along the Omani coastline. The bones and shells of green turtle are found associated with most graves; turtle skulls were placed near human skulls, with the rest of the turtle bones spread across the human skeleton (Salvatori 2007).

The bones of domesticates such as dog, sheep/goat and cattle have been found at a number of sites such as RA-6 and RH-5, suggesting that seasonal movements between the coast and inland areas may have occurred (Biagi *et al.* 1985; Biagi and Nisbet 1989, 1992, 1999; Biagi 1999). This is supported by the finds at the inland cemetery site of BHS-18, where two fish hooks were found in a cemetery (Kiesewetter *et al.* 2000). Carbon isotope analysis of human bone suggests that there was a significant marine component to their diet, perhaps indicating mobile herding communities making seasonal movements between the coastlines and interior. Whether this was to the Omani or UAE coast is unclear, since the site is equidistant from both; perhaps the site represents seasonal movements between both coastlines. Pastoralism was already established on the peninsula by a population that was largely aceramic. Evidence for domesticated herd animals date back to the ninth millennium BP at sites such as WTH (eg Uerpmann *et al.* 2000; Uerpmann and Uerpmann 2008; Uerpmann *et al.* 2009; McCorriston and Martin 2009). The origin of these domesticates is likely to be either the Levant or Africa, although the debate remains open (eg Uerpmann *et al.* 2009). Much later the full Neolithic farming package arrived from Africa bringing the “red stick burnished ware” typical of the Gash Delta in Sudan which appears around 4000BP (Tosi 1986; Edens and Wilkinson 1998).

These sites are predominantly found on the coastline, as opposed to sites on the Red Sea or in the Gulf which are often found some distance inland on palaeoshorelines. Those set further back are usually located next to wadis, which have prograded over time. The mangroves which most of these sites were exploiting are in part responsible for progradation of the shoreline, and many of these mangroves have now disappeared (eg Lézine *et al.* 2002).

Although most of the Neolithic structures recorded along the Omani coastline have been inferred from post holes, the c.7000BP sites at SWY have more substantial footings, delimited by large angular stones displaying similarities with the gulf sites (Charpentier *et al.* 2003). There is direct evidence of trading or possibly direct contact with Ubaid sites at a number of the UAE shell midden sites, where Ubaid pottery has been found (eg Beech and Elders 1999). This is often associated with locally produced pottery, and in some cases evidence of structures, although not as substantial as at the Kuwaiti Ubaid site of H-3, with the exception of MR-1 and MR-11 where stone structures have been found. Other evidence might also come from the site of Dosariyah, where evidence of plaster has been found, suggesting at least semi-permanent structures, and perhaps a technological link with Ubaid sites such as H-3 where plaster was utilised.

It is interesting to note that no shell midden sites have so far been discovered along the Iranian/Iraqi coastline in between Duan-1 and H-3. Is this a function of where archaeological survey work has been carried out, archaeological visibility, or that there really are no sites there? This side of the Gulf is very tectonically active (eg Page *et al.* 1979, Berberian and King 1981; Berberlan 1981; Reyss *et al.* 1999), and it might be that this has affected the archaeological visibility of the sites – either destroying the sites, or perhaps submerging them. It may be that the extent of archaeological survey along this coastline might not be as extensive as along other stretches of coastline.

So far no evidence of fish hooks has been found further south along the coast of Yemen, or into the Red Sea. However the broad geographic distribution of this type of find and its association with shell middens means that there is a distinct possibility that this technology may have made it all the way to the Red Sea. Net weights may suggest a potential link to sites along the Oman and UAE coastlines; however it might simply be a case of convergent technology. Similar lithic typologies have also been observed in both areas that might support contemporary links, although it might be a relict of earlier movements (either of people or ideas).

The Gulf sites of the UAE are fewer in number than those of the Omani coast. However there are some exceptional sites along this coastline, demonstrating a high and varied level of coastal resource exploitation, technology, ritual, and trade. As with many of the Omani sites, the majority of the UAE shell midden sites have fish hooks made of shell present, as well as other fishing tools such as net weights. However the site on Dalma Island (DA-11) demonstrates the use of a different form of net weight to that found in the Omani sites, the perforated disk (eg Beech 2003; Glover and Beech 2005). DA-11 (Dalma), another c.7000BP island site, has a similar array of pottery, albeit with less substantial structures, defined by postholes rather than stone walls. Domestic animals were also kept at the site, and fishing was an important activity (Flavin and Shephard 1994).

Another intriguing site is that of Akab from c.5900BP; this site has a clear coastal signal, with evidence for exploitation of pelagic tuna, perhaps necessitating the use of vessels (Méry *et al.* 2009). However the most extraordinary find was a platform of arranged dugong (a large marine mammal) bones, with beads and other ornament objects inserted between the bones (Méry *et al.* 2009). This level of ritual behaviour is not seen at any other shell midden sites in this region, and is only paralleled by the RH-5 site in Oman, where green turtle remains are a common grave good (Salvatori 2007).

Akab also features over 280 post holes, with many structures identified. Domestic dog, sheep, goat and cattle were all found at the site. Local raw material for lithics manufacture is poor therefore shell was used as a substitute; many scrapers and knives have been recovered from the site made from the bivalves *Callista erycina* and *Amiantis umbonella* (Mery *et al.* 2009). Pottery from the Mesopotamian Ubaid culture (located at the head of the Gulf) was also found at the site, indicating trade links or at the very least contact with Ubaid communities.

The Marawah Island group of sites (c.7000-6500BP) displays another variety of technology as buildings constructed with dry stone walls were found.

Pottery was also found at this site; both imported Ubaid and locally produced plaster vessels. This suggests a greater level of sedentism (or at least permanence in the landscape), both because of the structures, and specialised manufacture (Beech *et al.* 2005).

There appear to be fewer coastal sites along the coastline of the UAE than of Oman. However the sites which have been located and investigated have proved to be crucial to our understanding of the Neolithic Gulf, both in terms of technology, trade and ritual. Not only do they show evidence for trade, but the presence at many sites of domestic animals shows potential contacts with the interior. Indeed as already mentioned, the site of BHS-18 seems to demonstrate a contact between the coasts of the UAE and Oman. The evidence of trade with Ubaid communities raises the possibility that domesticates and farming practices moved into the region via this route.

Further into the Gulf the Saudi Arabian site of Dosariyah also dates to this period (c.7000BP), this time dominated by marine oysters. At this site a large quantity of Ubaid pottery was recovered, along with evidence of domestic sheep/goat and cattle. Semi-permanent structures were present, with post holes and plaster found at the site. Evidence for fishing such as fish hooks was also found (eg Burkholder 1972). The Qatari sites of Khor D and Khor FB (c.6500BP) have demonstrated mixed fish, marine and mangrove shellfish exploitation, with painted Ubaid potsherds (Inizan 1979).

A highly significant site for the period and region is the Kuwaiti site of H-3 (c.6500BP). Here evidence was found for long distance trade, such as obsidian from Anatolian and Caucasian sources. Although no remains of boats were found, it is highly probable that there was a seafaring community at this site. Pieces of bitumen were found with reed impressions in them, as if it had been used in the maintenance of a boat. This is supported both by a painted image of a boat on a ceramic disc, and a model ceramic boat. This site was home to a complex Neolithic village of stonewalled structures, with thousands of Ubaid pottery sherds found throughout. The bones of hunted and domestic sheep/goat and cattle were also recovered from the site (Carter

and Crawford 2003). It has been speculated that this site may have been in direct contact with other coastal sites around the Gulf (Biagi 2006). The presence of Ubaid pottery at MR-1, MR-11, DA-11, Dosariyah and Khor FB suggest at least trade contact with Ubaid sites. Whether the pots arrived at these sites via terrestrial or marine routes is unclear, but it would not be surprising if they came by sea given the wide trade networks of the Ubaid. The site of Al-Buhais (BHS-18) has strong evidence of coastal contact, not only the potential of trade but the movement of people (Uerpmann *et al.* 2006). This shows that people did not just move by sea or coastal routes, but also moved inland as part of wider landscape exploitation. Indeed if they possessed domesticates it may have been favourable to move in this way taking advantage of seasonal rains and food sources. Sites of this nature are not restricted to the Arabian Peninsula side of the Gulf either, evidenced by the site of Duan-1 on the coast of Pakistan (Biagi 2006). This is another site dominated by *Terebralia sp.*, however no evidence for fishing has yet been found.

As hinted at above, lithic technology could be used to infer links between sites over large distances. The Arabian Bifacial Tradition is an established typology in Arabian archaeology, characterized by stemmed points, foliates, and lanceolates (Edens and Wilkinson 1998). The ABT has been questioned (Charpentier 2004), but is still used as a convenient blanket label by the majority of researchers. It is made up of a number of distinct regional groups which all share a common ancestry (Edens 1988); variations include the frequency of bifacials (predominantly points) and distinctions in the bifacial elements such as pressure flaking (Zarins *et al.* 1981; Edens and Wilkinson 1998).

The sites from the eastern and western Red Sea were found to differ in terms of lithic technology; the key difference being the absence of the Arabian Bifacial Tradition on the western side. However obsidian is a key constituent of assemblages on both sides of the Red Sea, with geometric microliths present at many sites. The obsidian has a “smoky” dull appearance which superficially does not resemble obsidian (Zarins and Al-Badr 1986). Analysis

of potential sources for the obsidian suggests that transport of obsidian across the Red Sea may have occurred (Khalidi 2009), but is yet to be definitively proven.

The predominant lithics found associated with coastal sites along the Tihama Plain are quartzite debitage/lithics, small cores and primary cortexes, choppers, borers, groovers, piercers and awls. More rarely burins, small end scrapers, blades, use-retouched flakes, notches, transverse projectile points, backed blades, sickle blades, awls, blades, flakes, bifacially knapped tanged and lobed projectile points occur. Possible influences from the Horn of Africa might be present in South Arabia in the form of bifacial foliates and trihedral rods (Clark 1954; Rose 2006; Uerpmann 2009); however these may be local developments (Amirkhanov 1996; Uerpmann 2009). Fedele (1985; 2009) documents a local non-bifacial industry in the highlands of Yemen; and Uerpmann (1992) describe a distinct littoral tradition that includes elements of bifacial technology. Aside from obsidian the lithics of the Tihama Plain are composed of a variety of materials including: andesite, diabase, gabbro, ferruginous quartzite, basalt and greenstone (all of which have source areas in the eastern Tihama). Sandstone scoria and basalt grinding stones present with hand querns and larger basin types represented (Zarins and Al-Badr 1986).

The sites reviewed here have shown the great diversity and similarities of the shell middens across the region. They have a broad distribution and are predominantly located in (former) mangrove environments. Resources exploited can be broad and numerous, such as at Dosariyah, RH-6, Akab, or H-3, or more restricted such as at Duan-1 or Asfet. The key similarity is the exploitation of shellfish, with many sites also exploiting fish. These sites are almost always part of small groups of up to a dozen, or near to other sites further along the coast. The exception to this is the recently discovered sites on the Farasan Islands.

The evidence for prehistoric coastal resource exploitation along the coastlines of the Arabian Peninsula is compelling, with sites detected and dated to 8000-

4000BP. The sites are distributed both along the majority of Arabian Peninsula coastlines, and along adjacent coastlines. The discontinuity of distribution (areas where such sites have not been located) may be a function of the intensity of archaeological survey between areas, in those areas which have been surveyed they have been present. An added complexity to this is the archaeological visibility of sites; sites may have been destroyed, modified or buried by various processes. Compounding this is the fact that the coastlines have altered dramatically, as witnessed at sites on the Tihama Plain and at El-Gouna. This means that coastal sites are not necessarily located on modern shorelines and may be in less obvious locations. This may mean that important sites may have been overlooked by survey, if they have been carried out at all in these areas.

Contact between different areas has been demonstrated at a number of sites, most notably in the Gulf where widely distributed Ubaid pottery has been found. Less definitive typological evidence such as fish hooks made of shell, net weights, and obsidian lithics (especially the distinctive tanged bifacial arrowheads) could be interpreted as contact, trade/exchange or movement of people, but might also represent convergent evolution of technologies or be relicts of earlier movements. The important inland site of BHS-18 certainly demonstrates movement between inland and coastal environments. Whether the focus of subsistence was maritime or terrestrial is hard to ascertain. Certainly some sites are dominated by marine resources, whilst others show a mixture of marine and terrestrial, including domesticates. The number and size of shell midden sites is not suggestive of prolonged intensive activity, rather shorter seasonal visits. It is unlikely that a single model can be applied across the Peninsula, since each locale and site displays individual variations which lean one way or the other. The more likely scenario is of localised groups employing different subsistence strategies, which probably changed over time. Sea faring may have been important to some communities, such as H-3 in Kuwait, which whilst constructing permanent structures also employed ships for trade and/or subsistence. The presence of shell middens on the Farasan Islands implies open ocean voyaging, although whether the islands were occupied seasonally or year round is yet to be resolved. As discussed

the site of BHS-18 suggests the importance of both terrestrial and marine resources, but does not necessarily discount the use of water craft.

The dating of these sites is important, since many predate 6000BP, when sea levels stabilised at their modern levels. Earlier sites often located along inland palaeoshorelines demonstrate that coastal resource exploitation was a viable subsistence strategy which was employed prior to the stabilisation of sea levels. This could be used to support continuous exploitation through the Holocene rather than intensification. Their location inland also suggests a tectonic element, which has influenced the archaeological visibility of the sites. Given the size of the known sites it is unlikely that they were occupied for long periods, and may represent part of a more widespread exploitation strategy; exploiting broader coastal and terrestrial resources. It may well be that other contemporary sites are archaeologically less visible, either being underwater due to rising sea levels, or affected by taphonomic processes.

If this is not the case and the number of known sites are a true representation of the original sites, then it may be that there is an intensification of coastal exploitation between 6000-4000BP when the number of known sites increases. It may be that climate has had a profound effect on the exploitation strategies of prehistoric fisher gatherers, perhaps forcing intensification during this period, from the lower levels which preceded it. Until further research is undertaken no definite conclusions can be reached, and all scenarios must be considered as possible. However it is useful to consider all of the factors discussed above:

- Research bias
- Taphonomic bias
- Sea level change
- Climate change

- Changing strategies over time

Until recently the data presented here would support the theory of continued levels of exploitation through the Holocene, albeit with increasing fishing technology and the introduction of domesticates. New findings on the Farasan Islands have added another dimension to shell midden research in the region. The small number of published dates, together with evidence for a high density of sites is compelling evidence for Holocene intensification. However further research is needed to substantiate this.

2.3 The Farasan Islands

The Farasan Archipelago is located in the Southern Red Sea, in Saudi Arabian waters on the border with Yemen (Figure 6). It is made up of over 250 islands, the largest of which is Farasan Al-Kabir, followed by Sajid. Several references have been made to shell middens on the islands, including the surveys by Zarins *et al.* (1981), Jado and Zotl (1984), Bantan (1999) and most recently Bailey *et al.* (2007a, 2007b). The shell middens will be reviewed first, before looking at the nature of the islands.



Figure 6: Location of the Farasan Islands in the southern Red Sea.

An archaeological survey of the Tihama Plain (Zarins *et al.* 1981) first recorded the presence of shell middens on the Farasan Islands. A radiocarbon date obtained from one of the sites yielded a date of 5335 ± 225 BP. However at this time the full extent of the sites was not known and only a brief mention was given to them. Several brief mentions have been made by projects and surveys on the islands, which have resulted in the radiocarbon dating of several sites in Janaba Bay. These are: from the Deputy Ministry of Antiquities and Museums (1990) Level 3: 5235 ± 225 BP; Level 3: 4810 ± 170 BP; Level 2: 2410 ± 100 BP; and from a geological survey 5400 ± 250 BP (UCL 435) (Bantan 1999).

In 2006 a survey team (of the Southern Red Sea Project) arrived at the islands with the knowledge of the existence of these sites (Bailey *et al.* 2007a, 2007b). They set out to map them with the intention of being able to create associations between these prominent sites and their position within the landscape. Armed with this they hoped to use the knowledge to search for sites on drowned coastlines underwater. During a one month field season

they mapped over 1000 sites on land, the majority of which were shell middens. A series of test pits were excavated at two shell midden sites, consisting of 50cm wide step trenches down the flank of each site (Figure 7). These revealed:

“Stratified and compacted layers of marine shells with variable degrees of fragmentation are intercalated with ashy lenses representing the remains of fireplaces, indicating slow incremental growth of the mounds and repeated use over periods of centuries or more” (Bailey *et al.* 2007a, p7).

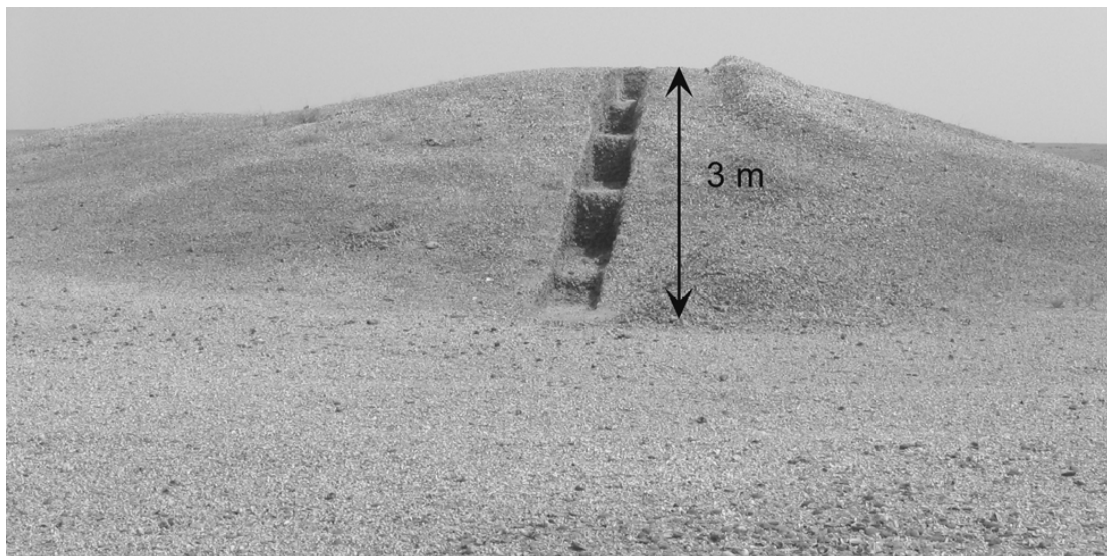


Figure 7: Step trench down the side of a shell mound in southern Saqid excavated in 2006 (Bailey *et al.* 2007a).

These mounds were therefore positively identified as anthropogenic, and the true scale of their density and distribution recognised. No known shell midden complex is composed of this number of sites, and in the densities recorded here. It was also recognised that these sites follow long palaeoshorelines.

Only a small portion of the islands were surveyed, and methods of surveying differed greatly between survey teams. Some recorded GPS single points for groups of sites, whilst others assigned single GPS points to each site. The areas surveyed in 2006 are shown in Figure 8.

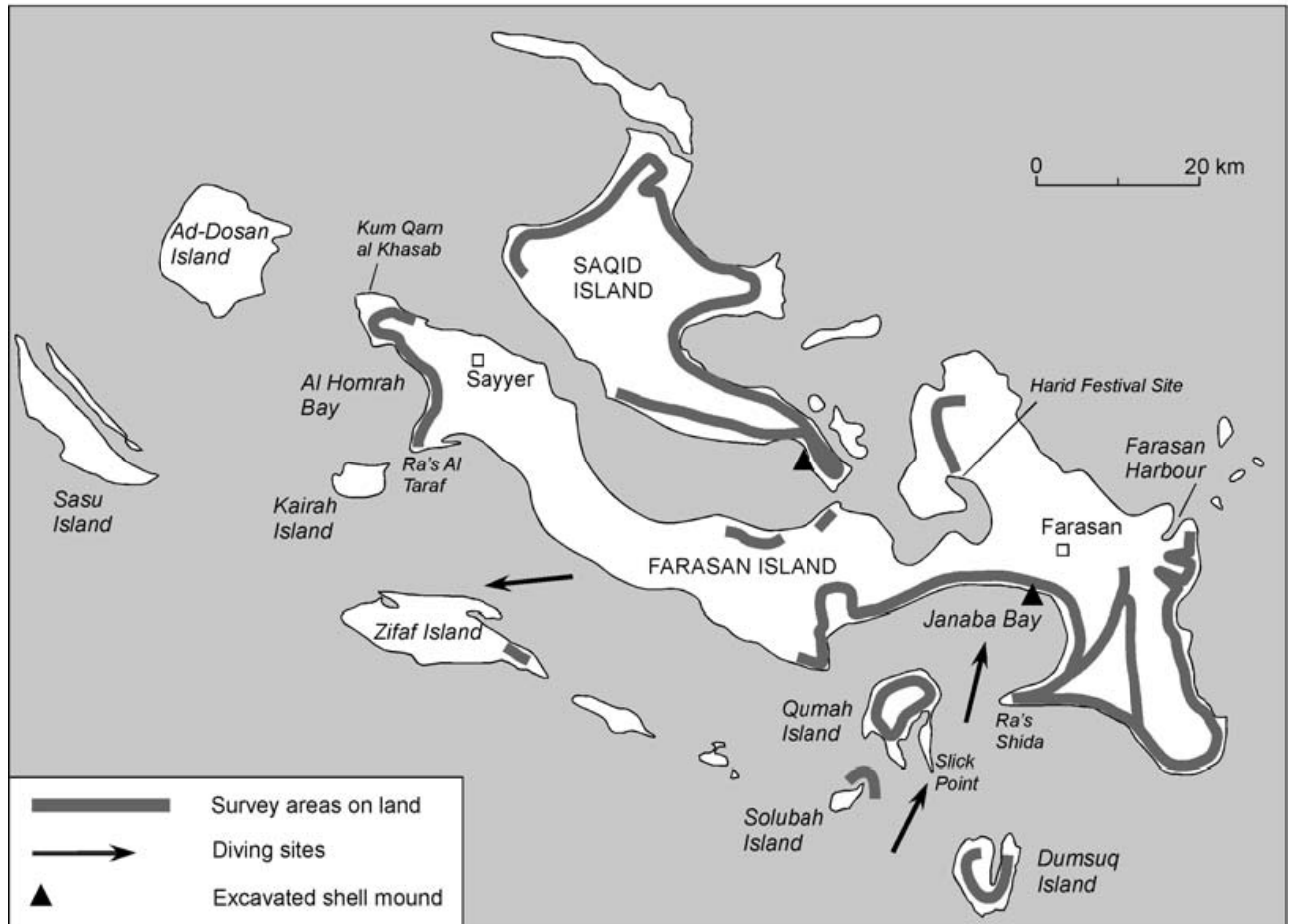


Figure 8: Areas of the Farasan Islands Surveyed in 2006 (Bailey *et al.* 2007a, 2007b).

At 8Kyr BP sea level would have been c.20m lower, and the Farasans would have been connected to the mainland (Bailey *et al.* 2007a). However no sites have yet been dated to this period, leaving a hiatus between the lithics dated by typology to the Middle Stone Age, and the shell midden sites radiocarbon dated to 5335 ± 225 BP (Zarins and Al-Badr 1985). Since the Holocene presence of humans on the islands post-dates the separation of the islands from the mainland, this would imply the use of boats. The 5335 BP date suggest that humans only re-inhabited the islands after sea levels had stabilised c.6Kyr BP, meaning that the distance between the mainland and the islands would have been approximately 40km. There are several small islands in the intervening waters, however given that in perfect conditions a 6ft tall person standing at sea level can only see 2.8 miles (Rousmaniere 1999) the journey would entail open ocean skills and perhaps prior knowledge of the

islands. Earlier sites may exist on the islands, however these have yet to be identified or dated.

The Red Sea is a young, narrow ocean and a major evaporite basin where salt tectonics have played a major role in forming local geological structures. The Farasan Archipelago share a common geological history with much of the rest of the basin. Salt deposits 2-4km thick over the majority of the region, and up to 5km thick in restricted areas. Heaton *et al.* (1995) have carried out extensive interpretation of the area immediately to the south of the Farasans in Yemeni territory using seismic data from the oil industry. From this work it is possible to extrapolate north to the Farasan archipelago in an attempt to understand the underlying geology and forces which have formed and shaped the islands, and which are still shaping them. The geology in this part of the Red Sea is broadly continuous, with similar formations occurring on both sides of the continental shelf, and extending from the Bab-al-Mandab up to the northern tip of the Farasan Islands.

Salt domes (often termed diapirs or canopies) are one of the key active tectonic processes at work on the Farasan Islands; they have resulted in changes to relative sea level through warping of the land surface (Figure 9). This has created a number of palaeoshorelines visible above sea level, with the possibility of further features below sea level. Salt domes form by a complex process where pressure exerted by tectonic forces (such as rifting) causes massive faulting across vast areas, often extending over the continental shelf and beyond. These fault-lines allow water (which may originate either from the surface, or from pockets trapped in porous rock at depth) to penetrate to great depths through the crust and into the salt bearing layers; the addition of water under the huge pressures and high temperatures that the salt is under, results in the salt becoming fluid and having increased mobility potential. The mobile salt is then free to exploit weaknesses in the rock and migrate; these weak spots are predominantly the fault lines which allowed the water to penetrate the salt. The salt migrates along these weaknesses, following the pressure gradient, which will normally lead it up towards the surface. The salt will eventually reach a depth where the weight

of the overlying rock is low enough that the salt can push it up and expand into the surrounding weaker bedding planes. Giving impetus to this process will be the declining temperature of the salt, since the temperature gradient will also be reducing towards the surface. This region has one of the highest geothermal temperature gradients in the world at 77°C/Km (compared to a global average of 27°C/Km) (Heaton *et al.* 1995). As more salt is pushed up from below, the overburden is further pushed upwards and outward, and the salt pushes further into the bedding planes, increasing the size of the forming salt dome. Where the salt withdraws, the overburden slumps forming withdrawal basins.

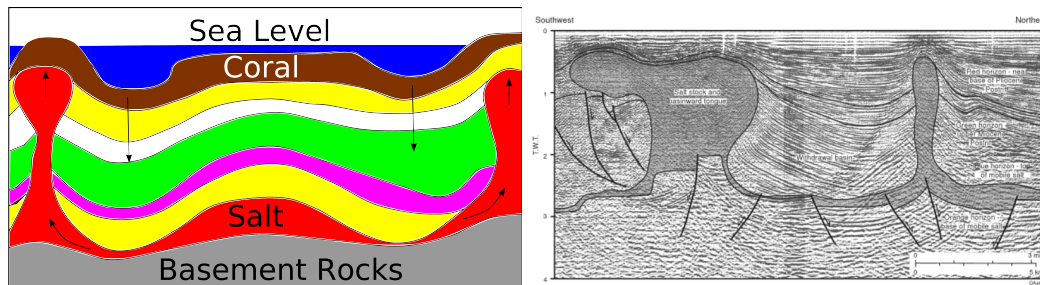


Figure 9: Salt tectonics – Left, schematic of salt diapir formation; right, interpreted geophysics of salt diapir (Heaton *et al.* 1996).

It is hard to verify whether salt tectonics are responsible for all of the inland palaeocoastlines on which shell middens have been found, indeed these investigations are not within the scope of this project. The extent to which the salt extends under the mainland is unknown, although observations, en-route to fieldwork for this PhD, suggest that there is extensive micro tectonics active in the Jizan region, resulting in the uplift of small domes. The time scales of these events must be short, since many buildings located on these small domes were at perilous angles, suggesting a timeframe of 20-50 years. This is evidence that the Jizan area may well be subject to similar tectonic forces as the Farasan Islands. It is possible that these forces have also affected the Tihama Plain resulting in palaeoshorelines on which many of the sites are located. However considering the uniformity of much of the uplift it is likely that more widespread rifting tectonics are the underlying causes.

The Farasan Islands and their Yemeni neighbours have had extensive geological research carried out (Bantan 1999; Heaton *et al.* 1995). This has resulted in the conclusion that salt tectonics are still active, and in the case of the Farasans, that they are most likely responsible for the uplift and palaeoshorelines along which many shell middens are found (Bantan 1999). For other regions of the Red Sea the origin of the palaeoshorelines is likely to be rifting, but salt tectonics cannot be ruled out until further research is carried out. This is particularly relevant to the Egyptian sites at El Gouna, where a palaeocoastline is inferred from the inland position of the middens, although no actual evidence of that palaeocoastline was documented (Vermeersch *et al.* 2005a, 2005b). In the case of Asfat (Mayer and Beyin 2009) it has already been suggested that these are inland shell middens, and their inland location was deliberate, possibly a response to a shift in climate which necessitated an intensification of coastal resource exploitation in addition to the terrestrial resources already exploited, possibly herding.

Hydro-isostasy and the active tectonics of the region could also be playing a role in the uplift seen in the region. Whilst hydro-isostasy has been responsible for uplift up to a couple of meters (eg Dickinson 2000; 2003; 2004), rifting tectonics are likely to be the driving force beneath the uplift of up to 20m experienced by mid-Holocene shell middens the length of the Red Sea. Hydroisostasy is an effect caused by the increased loading of water in the oceans due to melt water (eg Dickinson 2000; 2003; 2004). This extra weight of the water depresses the lithosphere resulting in the distortion of the adjacent coastlines (Figure 10), following a similar trend to the glacial isostasy described in areas such as northern Europe. This has been calculated to result in a 30m depression of the sea bed for every 100m of sea level rise. However the water is only 20-40m deep around the Farasans. Added to this is the fact that the islands have risen rather than sunk, suggesting that salt tectonics are the primary influence. Where the sea bed is depressed, there is often a fore-bulge of the displaced mantle, resulting in uplift away from the centre of depression. In other regions of the world this is measured in the order of single digit metres, often no more than 2-3m. Therefore the uplift up

and down the Red Sea must be due to wider ranging tectonics associated with the rifting.

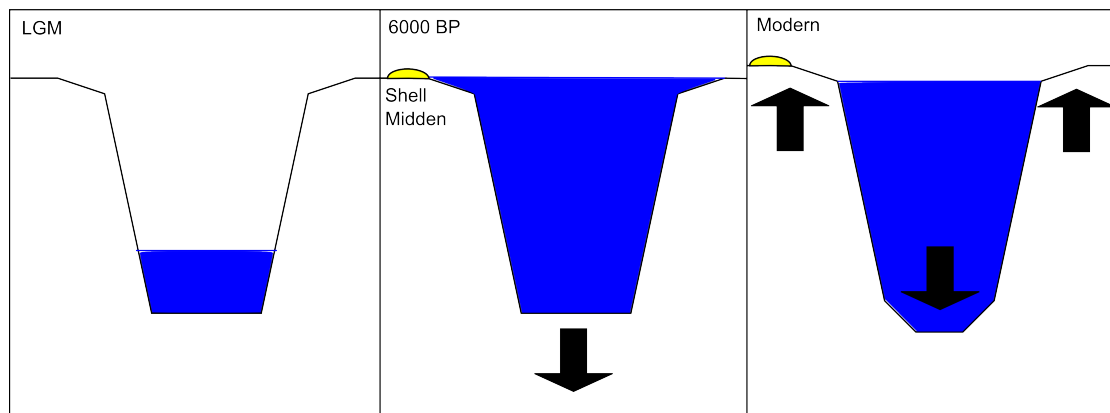


Figure 10: The effects of hydroisostasy. During the LGM water is locked in the ice sheets and sea level is low. At c.6000 BP the ice has melted and sea level rises to its maximum, shell middens accumulate along the shoreline. The weight of the water impacts upon the lithosphere, resulting in readjustment to modern conditions. The 6000 BP shell middens are stranded inland on palaeoshorelines.

The salt tectonics of this region add a complicating dimension, since the increased loading will also add pressure to the salt at depth as well as to existing salt domes, potentially forcing further mobilisation and deformation of the salt deposits and ultimately the land surface. This can result both in highly localised movements in the coastlines, and broader regional changes. In the cases of the Red Sea and Gulf this seems to have been highly localised. For example in the Gulf no detectable change in sea level has occurred since sea level stabilisation at the site of MR-1 and MR-11. However a coastal change of several kilometres has been detected down the coast in Qatar. Likewise evidence from the Farasan Islands presented by Bailey *et al.* (2007a, 2007b) suggest that some shell middens are still located on the modern coastline, where there appears to have been no discernable change in relative sea level. However only several kilometres down the coast there are sites located a couple of kilometres inland; the authors state that the coastline looks visibly warped, rising away from the coastline (Bailey *et al.* 2007a). The extent to which hydroisostasy and salt tectonics are linked is at present poorly resolved, but it seems logical that it has had some impact.

The Farasan Islands have a rich range of coastal resources. At 40km from the mainland and necessitating a potentially hazardous sea crossing beyond the visible horizon to reach, the attractions of the islands must therefore have been large. The islands have a surprisingly high species diversity, with 87 floral species being recorded by El-Demerdash (1996) – and thus greater resource availability than might at first be anticipated (see also Alwelaie *et al.* 1993). These are present in seven habitat types, namely silty runnels, palm orchards, rocky plains (Figure 11), rocky plateau crevices, coastal sand dunes, sand plains, and mangroves (Figure 12). Palm orchards are often seen as a relatively modern innovation, however the period in which date palms were introduced to the islands is unknown; the earliest evidence in the UAE is dated to 7000 BP (Beech 2003). The species present take advantage of favourable locations, and flourish after the infrequent rainfall. They offer a more diverse resource than would otherwise be apparent to any foragers on the islands.



Figure 11: View over Janaba Bay East from raised ground (photo H. Robson).



Figure 12: View over Gandeel Peninsula (photo H. Robson).

The coastal margin provides a more reliable resource, with rainfall on the islands being unreliable both in terms of regularity and quantity; a figure of 70mm/yr is often quoted (eg El-Demerdash & Zilay 1994, El-Demerdash 1996) however in 2008 locals believed it had not rained on the islands for between 10 and 40 years depending on the source (pers. obs. 2008). In late 2008 there was an intense rainstorm, however no records are available for how much rain fell. In March 2009 evidence on the islands suggested that there was significant surface runoff from this event, despite the bedrock being of limestone. The vegetation on the islands certainly benefited from the rainfall, and there were many more plants visible than in the previous year; apparently lifeless bushes had burst into life.

Based on extrapolated climatic data from Jizan, the islands have a long hot season from April to October (mean maximum air temperature 38.5°C in July; mean minimum air temperature 29.7°C), and a short mild one from November to March (30.5°C mean maximum air temperature in January; mean minimum air temperature 21.4°C). This forms part of a dry tropical climate regime dominated by hyper-aridity (El-Demerdash 1996).

The islands are very important for bird migrations, which stop off on the islands en-route between Africa and Eurasia; these form an important supplement to local diet. These migrations are by their nature very seasonal. Other animals on the islands include an endemic sub-species of *Gazella erlangeri*, cut off on the islands by rising sea level. Exploitable marine meat sources include an abundance of shellfish, fish, turtles, and cetaceans.

The Farasan Islands have a number of established mangroves, these are dominated by *Avicennia* trees, which have a fast regrowth rate and are therefore suitable for fuel as long as anthropogenic pressure is not too high (El-Demerdash 1996). The tree is also hard wearing, making it suitable for construction, although not for boards due to its irregular multibranched stem (Biagi and Nisbet 2006). The mud of the mangroves support a productive food chain, including the gastropod *Terebralia palustris* (mangrove whelk) and other shellfish provide an important resource.

There is a wide variety of edible fish including grouper and sea bream which are readily available close to shore. These are supplemented by ray, turtle, porpoise, the occasional beached whale, shark, and abundant shellfish. Shellfish species include the gastropods *Strombus fasciatus* and *Turbo sp.*, and various murex and conch species most commonly *Chicoreus ramosus* and *Pleuroploca trapezium.*; bivalves include *Tridactna sp.*, *Spondylus marisrubri.*, *Chama reflexa.*, various *Pinctada sp.* (commonly *Pinctada nigra*) and *Barbatia sp.* (commonly *Barbatia setigera*) amongst others.

Inland a variety of small shrubs and herbs grow, but are limited by low moisture availability (eg El-Demerdash *et al.* 1994; El-Demerdash 1996). However this is sufficient to support a population of endemic gazelle and pockets of larger shrubs and small trees are supported where the water table is closer to the surface.

Lowering of sea level during the Quaternary resulted in the narrowing of the Bab-al-Mandab straits, which reduced the inflow of water from the Indian Ocean. This resulted in a sharp rise in salinity of the Red Sea to ~50-55%;

however the fact that it never went past this level seems to demonstrate that there was input of less saline water preventing the basin from drying out (eg Bailey *et al.* 2007a; 2007b). This is thought to indicate that the Bab-al-Mandab straits never closed (Siddall *et al.* 2004). However, it has been proposed that the release of hydro-static head on inland aquifers may have resulted in a higher aquifer discharge rate into the Red Sea (Faure *et al.* 2002). What rates this discharge reached has still not yet been resolved, and thus it is not known how this input impacted upon Red Sea salinity during periods of lower sea level.

The Red Sea was hyper saline until sea level rise increased input through the Bab-al-Mandab straits at about 17kya. The sea at this time would have had reduced biodiversity, and has only reached present salinity levels by around 13-9kya (Arz *et al.* 2003). It is important to note that the Red Sea was probably not as barren of life at these high salinities as may appear, since there are many species endemic to the Red Sea which have hyper salinity tolerance (Oilver pers. com. 2008). Following rising sea levels, the islands became cut off from the mainland, with the shelf in between reaching a maximum depth of 40m, with an average of 20-30m (Bailey *et al.* 2007a, 2007b).

The Farasan islands demonstrate a wide range of readily exploitable coastal resources. The presence of large numbers of prehistoric shell mounds has been demonstrated, showing that the resources on the islands represented an attractive and viable subsistence strategy.

2.4 Chapter Summary

The Farasan Islands have demonstrated an assemblage contrasting to any other on the Arabian Peninsula. The key similarities are the timings, and that they are located on palaeoshorelines, mirroring those on the adjacent Tihama Plain and more broadly in the Red Sea. However the scale of the sites (both individual size and number) is very suggestive of a period of intensification of shellfish exploitation. The good archaeological visibility lends these sites to

more intensive investigation, both in order to investigate the temporal and spatial distribution of sites, and the formation processes at work within individual sites.

The presence of shell middens which predate modern sea levels is a result of the active tectonics of the region. These sites show that coastal resource exploitation was happening when sea levels were lower, but a key question remains of whether these strategies would have been viable before 13'000-9000BP when salinities in the Red Sea would have been higher.

Intensification of shellfish exploitation in the in the Red Sea is not obvious due to the long continuous nature of mainland activity, and that it was part of a wider subsistence strategy. The only real sign of intensification are the numerous sites on the Farasan Islands, and these are in isolation.

Chapter 3

Climate Background

3.1 Holocene Climate of the Arabian Peninsula

The need for a robust model of climate has been made clear in the introduction. Social and economic responses to climatic deterioration could have resulted in an intensification of coastal resource exploitation, particularly after the Holocene Climatic Optimum of c.8000-6000BP (eg Parker *et al.* 2006a; 2006b). The climate of the Arabian Peninsula has been the subject of a number of climate studies; however the overall interpretation for the region is patchy due to a concentration of work in some areas and dearth of research in others. This chapter aims to synthesise a range of current research and evidence from a variety of climate proxies in order to put Holocene shellfish exploitation on the Arabian Peninsula and adjacent coastlines into context.

High resolution records from across the globe document fluctuations in climate on a range of scales from annual to millennial. Fossil coral in the Red Sea raise the possibility of high resolution annual climate reconstruction, perhaps for the entire Quaternary (eg Felis and Rimbu 2009). In terms of shell midden research annual data are not necessarily needed to assess human responses to climate change and the extent to which shellfish and other coastal resources were exploited. For example, a year of drought might force people to move further afield in search of resources needed for survival. But the likelihood is that they will return the next year after the drought has ended. This event will not necessarily be visible in the archaeological record.

There are exceptions to this; micromorphological analysis of the stratigraphy of a site can in some cases reveal seasonal events. Up to twenty occupation layers have been found in the Patagonian sites of Terra del Fuego (Villagran 2011), each separated by a thin lens of sand laid down during abandonment. Larger events have also been found in some shell middens close to the study area, but these have yet to be quantified (Vermeersch *et al.* 2005a and 2005b).

In most cases this is not possible, and even if it were dating techniques are generally not refined enough to align the two records. For the purposes of this study centennial time scales will have to suffice, since inaccuracies in radiocarbon dating result in an error equivalent of up to several hundred years of uncertainty.

During the Holocene the Red Sea and Arabian Peninsula experienced dramatic shifts in climate, in line with those experienced in other areas. However as with many regions this is complicated by the interaction of more than one climate systems. The climate of the Arabian Peninsula is characterised by interactions at the Inter Tropical Convergence Zone (ITCZ) of the Indian Ocean Monsoon (IOM), Asian Summer Monsoon (ASM), and the eastern Mediterranean climate system (winter storm tracks). These have fluctuated greatly, resulting in a climate which has rarely been stable, and is characterised by movements of the contact fronts between these systems (eg Fleitmann *et al.* 2007; Arz *et al.* 2003; Edelman-Frustenburg *et al.* 2009). Attempts have been made to assess this (Figure 13), but these are often general and of low resolution.

Although it is beyond the remit of this thesis it is useful to consider that another key consideration in the refinement the climate models for the region is the complicated combination of land masses, variable topography and water bodies. The hardest task is tying all of this proxy data into a coherent model, which accounts for local variations and microclimates which can complicate the picture (eg Fleitmann *et al.* 2007).

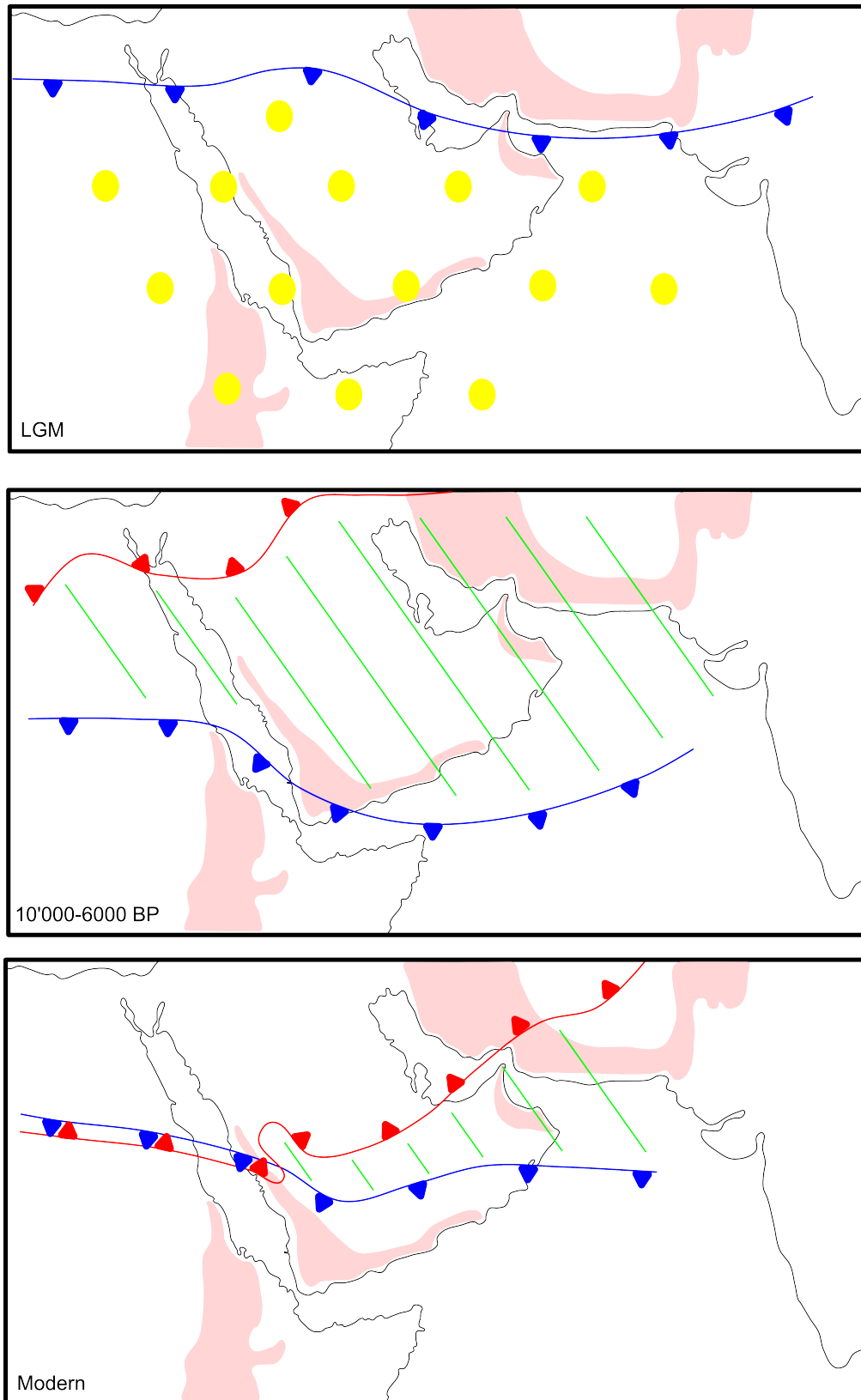


Figure 13: Holocene climate fronts across the Arabian Peninsula. Shaded red areas are high relief. Blue fronts are Mediterranean winter storms moving down from the North; Red fronts are monsoons from the south. Yellow dots indicate arid areas where neither system reach. Green shading is land influenced by both systems (adapted from Sanlaville 2000).

For the purposes of this review shell midden sites have been grouped by area; climate trends for each of these general areas have been compiled using data available in the literature (Figure 14 and Table 2). Rather than using temperature or precipitation curves, which are variable and can be ambiguous, climate zones have been used, referring to either arid, severe arid, humid and humid optimum conditions. These are positioned at breaks in the climate, where climate has swung from one zone to another but ignoring any transition since these tend to be highly variable between records and spatially discontinuous. This may be over-simplistic, but it gives a good general comparison against which to view the earliest activity at shell midden sites. There is relatively good data for Oman, where a number of caves, marine cores, and lacustrine sediments have provided a good chronology of climate through the Holocene. The UAE has had a lot of work undertaken on lacustrine sediments providing useful data. The Arabian Gulf has been less intensively investigated; therefore the available data has been supplemented by extrapolating data from the UAE, with the exception of Kuwait, where limited data is available. Yemen is relatively poorly understood, with only a handful of lacustrine sequences analysed to date. The Red Sea is complex, because of the long narrow nature of the sea, and the fact that it is sandwiched between two large continental areas – which are presently dominated by desert with high topography complicating the picture. Data for this area comes from a handful of marine cores. For the Egyptian site of El Gouna high resolution data is available from lacustrine deposits inland, as well as the Red Sea marine cores. The Pakistani site of Duan has a relatively well understood chronology both from marine and terrestrial proxies.

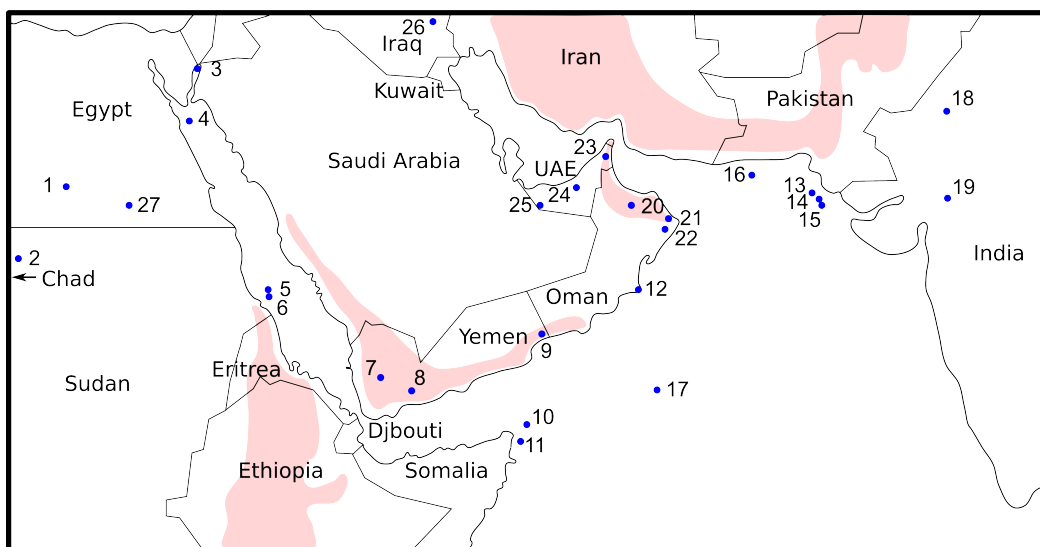


Figure 14: *Location of climate proxy data (for references see table 2).*

Region	Site Name	Country	Reference	Number on Map	Proxy
Africa	Nile	Egypt	Bubenzner and Riemer 2007	1	Lacustrine, Riverine
Africa	Yoa	Chad	Lezine 2009	2	Lacustrine
Red Sea			Arz <i>et al.</i> 2004	3	Marine
Red Sea			Arz <i>et al.</i> 2004	4	Marine
Red Sea			Arz <i>et al.</i> 2004	5	Marine
Red Sea			Edelman-furstenberg <i>et al.</i> 2008	6	Marine
Yemen	Dhamar	Yemen	Davies 2006	7	Lacustrine
Yemen	Ramlat as Sab'atayn	Yemen	Lezine <i>et al.</i> 1998	8	Lacustrine
Yemen	Qunf and Defore Cave	Yemen	Burns <i>et al.</i> 2002; Fleitmann <i>et al.</i> 2003; Fleitmann <i>et al.</i> 2004	9	Cave
Sudan	Dimarshim Cave	Sudan	Fleitmann <i>et al.</i> 2007	10	Cave
Indian Ocean		Sudan	Jung <i>et al.</i> 2002, 2004a	11	Marine
Indian Ocean		Oman	Gupta <i>et al.</i> 2003	12	Marine
Indian Ocean		Pakistan	Von Rad <i>et al.</i> 1999	13	Marine
Indian Ocean		Pakistan	Straubwasser <i>et al.</i> 2002, 2003	14	Marine
Indian Ocean		Pakistan	Schulz <i>et al.</i> 1998	15	Marine
Indian Ocean		Pakistan	Lezine 2009	16	Marine
Indian Ocean			Sirocko <i>et al.</i> 1993, 1996	17	Marine
India	Lunkaransar	India	Enzel <i>et al.</i> , 1999	18	
India			Prasad <i>et al.</i> 1997	19	
Oman	Hotti Cave	Oman	Neff <i>et al.</i> 2001, Fleitmann <i>et al.</i> 2007	20	Cave
Oman	Kwar al Jaramah	Oman	Lezine 2009	21	Pollen
Oman	Wahiba Sands	Oman	Radies <i>et al.</i> 2004	22	
UAE	Awafi	UAE	Parker <i>et al.</i> 2004, 2006a	23	Lacustrine
UAE	Rub' al Khali	UAE	McClure 1976	24	Lacustrine
UAE	Rub' al Khali	UAE	McClure 1976	25	Lacustrine
Mesopotamia			Riehl <i>et al.</i> 2009	26	Pedogenic, Archaeobotanical, Climatological
Sahara		Egypt	Kuper and Kropelin 2006	27	Multiple terrestrial

Table 2: Table of climate proxies and references

The approximate locations of the climate proxy data outlined above have been shown on a map in Figure 14. The details of each proxy are outlined in Table 2, along with citations for the original sources; some of these papers describe more than one proxy data set. The list of references is not exhaustive and a number of other key papers were also consulted but have not been included in Figure 14 and Table 2 due to their sites being located beyond the study area or having a broad temporal span which might hide changes in climate on a smaller scale such as this. These include Gasse (2000), Goodbred and Kuehl (2000), Leuschner and Sirocko (2000), Jung *et al.* (2001), Lamb (2001), Morrill *et al.* (2003), Hoelzmann *et al.* (2004), Jung *et al.* (2004b), Radies *et al.* (2005), Rohling and Pälike (2005), Prasad and Enzel (2006), Thamban *et al.* (2007), Parker and Goudie (2008) and Lézine *et al.* (2010).

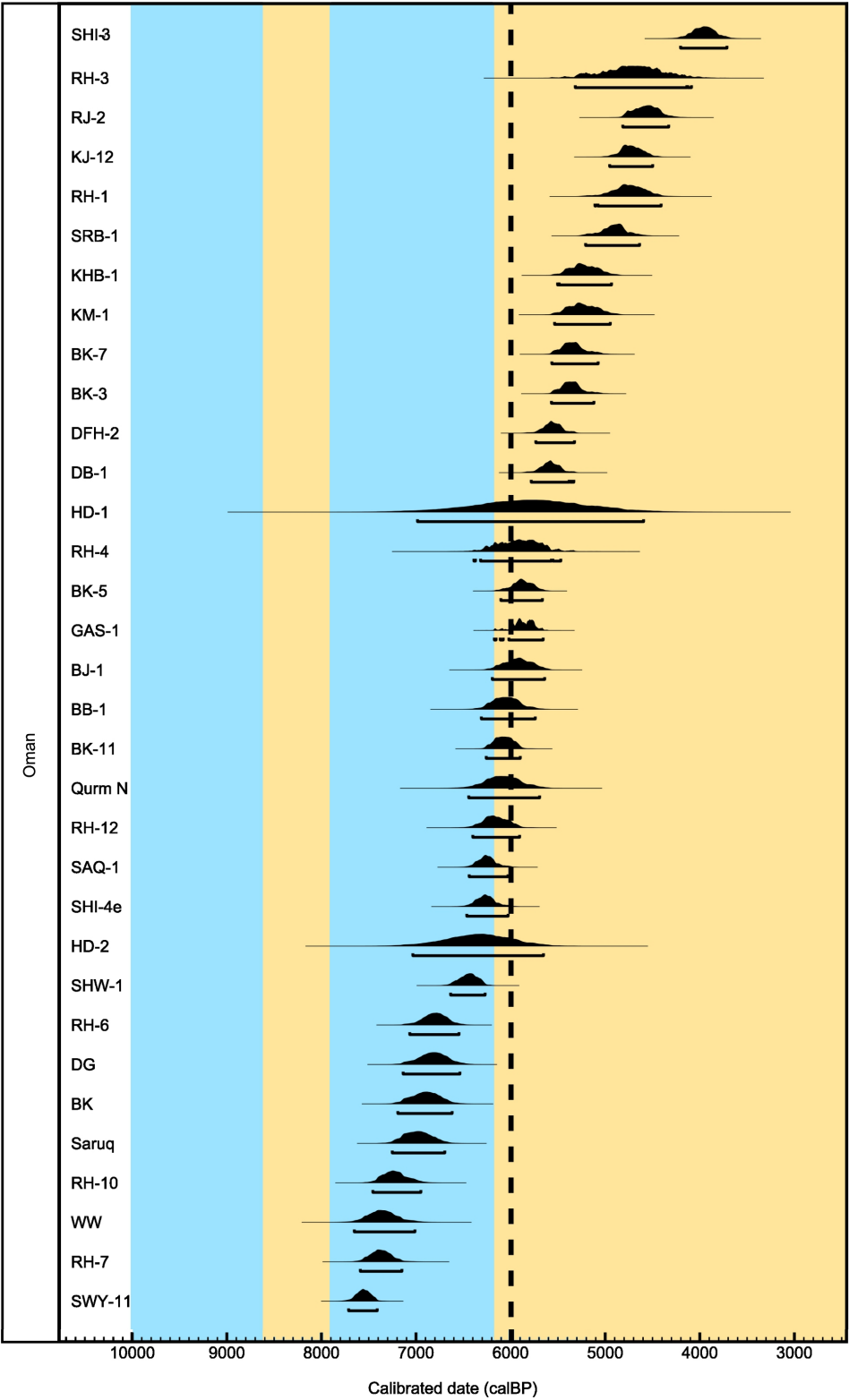
Reconstructing the climate of the Arabian Peninsula is a complicated task, involving the piecing together of many different climate proxies. However there are significant gaps in this proxy data, both spatially and temporally. Spatially there are many large areas in which no proxies have yet been found or analysed. Temporally a significant number of proxy records exhibit hiatus caused by erosion or cessation of deposition, in addition the temporal extent of this data also varies, with many covering different periods of time. Piecing these together has been a problem, and there is no right way of doing it. Areas which are geographically very close, such as the Saudi Arabian and Yemeni shell middens probably experienced a similar, if not the same, climate (Figure 13). However the Saudi sites are situated closer to the location of a marine sediment core which provides good proxy data, whilst the Yemeni sites are located closer the lacustrine and peat sediments in the mountains which have provided useful but more restricted climate data. Therefore the sites have been assigned a climate signal according to the closest palaeoclimate data available. Whilst on a local scale this might not necessarily be the most accurate method, on a broader regional scale the data show some interesting trends.

In Figure 15 these data are combined with those of Figure 5, using the earliest

dates obtained at each site, to depict the broad trends of climate against the earliest (known) occupation at each shell midden site. As discussed above these climatic trends are simplified to arid, severe arid, humid, and humid optimum phases. The timing of the changes in these phases is accurate according to the most reliable proxy data in the area; these timings will vary geographically.

For the Red Sea, starting at Eritrea, there are clear climatic perturbations starting at around c.8200BP, presumably the result of movements in the monsoon. Although the climate does not fully switch to arid conditions until c.6800BP, these perturbations precede aridification in Yemen at c.7000BP, and Saudi Arabia at c.6200BP, before the onset of arid conditions in Egypt at c.5200BP. This data would suggest that the end of the Holocene humid period was manifested by the gradual aridification spreading up the Red Sea or by the retreat of the IOM, whilst the MWS still influenced the site of El-Gouna until c.5200BP. Putting exact dates on events such as this is speculative, since local conditions can influence proxy. Different climate proxies are also capable of giving different levels of information, for example in Oman, Yemen and the Horn of Africa there are cave records which give precise information on rainfall. Likewise the marine core, which has been used for the Saudi climate, uses changes in the species of foraminifera in the core to suggest that the episode of aridification experienced intensification between c.4500-3200BP. It is likely that this would also have been felt further along the Tihama Plain in Yemen, which coincides with the dates of many sites here if the climate data is extrapolated across the area.

Figure 15 plots the known and dated prehistoric shell middens (reviewed in the previous chapter) against these climate variations. The dates are shown with their associated error, and it is important to note that these are the earliest dates from each site. Phases of climate are colour coded, yellow for arid, dark yellow for hyper-arid, blue for humid and dark blue for humid optimum. The stabilisation of sea level at c.6000BP is highlighted by the dashed line.



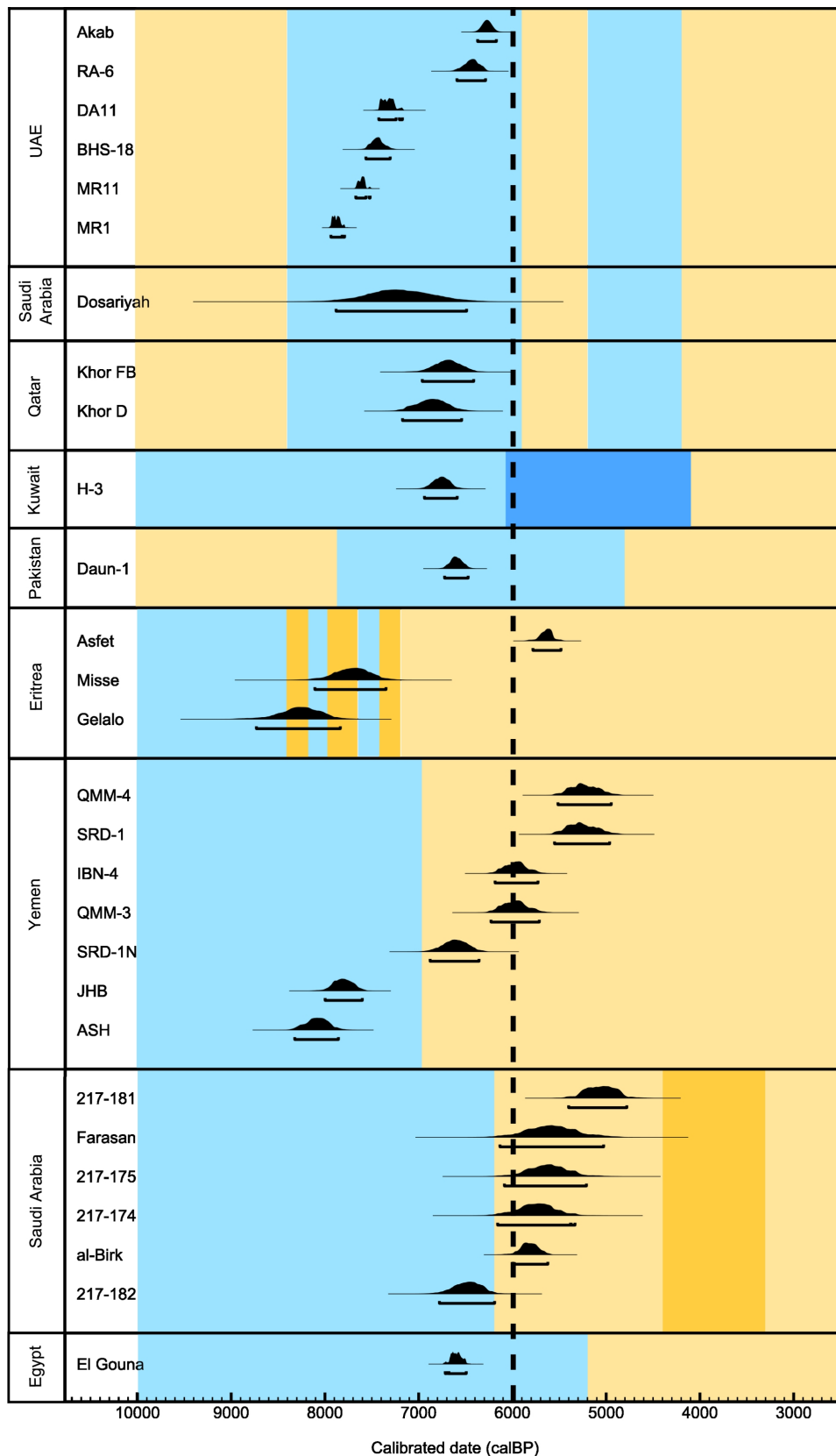


Figure 15: Dated shell middens of the Arabian Peninsula and climatic variations. Dates are calibrated BP. Blue shading indicates Humid climate, Dark Blue is Humid Optimum, Yellow is Arid, and Dark Yellow is Severe Arid phase. For climate data sources see Figure 11 and 13; for shell midden timings see Figure 6.

This diagram allows a number of key issues to be visualised. First it reinforces the data reviewed in the previous chapter concerning sea level change and shell midden formation. This suggests both a pre-adaptation to shellfish gathering around the Arabian Peninsula prior to c.6000BP, and that active tectonics has resulted in the uplift of many sites.

More pertinent to this chapter is the involvement of climate in the emergence of shellfish gathering communities in the region (eg Tosi 1985). On first inspection the initiation of shell midden building in each region seems to be associated with humid conditions, rather than arid. This strongly suggests that deteriorating climate was not a driving force in shellfish exploitation. However on the Farasan Islands the huge number of sites found is very suggestive of intensification, and does follow on from a change in climate. There is not a concentration of sites quite like it on or around the Arabian Peninsula. Further work needs undertaking to determine whether earlier sites exist on the islands, but preliminary observations are persuasive.

The earliest shell midden sites in the region are present at c.8000BP when sea levels would have been c.20m lower (eg Bailey *et al.* 2007a). It has also been shown that uplift along many coastlines of the Arabian Peninsula has been up to (and probably exceeding in places) 20m. It therefore seems probable that these are the earliest archaeologically visible sites of the Holocene, rather than the first. Complicating the scenario is Red Sea salinity, which is thought to have stabilised at near present levels between 9000-12000BP (Arz *et al.* 2003). Many shellfish species are endemic to the Red Sea and will tolerate hyper-salinities (Oliver pers. comm. 2008); however it is not known how salinity impacts on growth rate, species density, or recruitment. It is therefore feasible that these sites may be among the earliest to take advantage of shellfish populations after they had recovered from hyper-saline conditions. This means that finding a link between the initiation of shellfish exploitation in the region and climate is at this time unattainable, because the date of initiation is likely to predate 8000BP and is therefore unknown.

The next line of evidence to interrogate is whether the spatial and temporal distribution of shell middens in the region has been impacted upon by climate. Addressing these criteria Oman and the Saudi Arabian Red Sea stand out both suggesting intensification. In Oman a third of sites were initiated during the transition to more arid climate, and a greater proportion in Saudi Arabia. However these two clusters of sites also coincide with the stabilisation of modern sea levels c.6000BP. Therefore this could be a product of archaeological visibility, with a greater chance of sites survival.

However climate has also been implicated in the abandonment of certain areas due to hyper-aridity. The “Dark Millennium” of the UAE was thought to have been one such event, between c.6000-5000BP (eg Uerpmann 2002, 2003). Proxy records suggest an intense aridification of the UAE (eg Parker *et al.* 2006a); archaeological sites appeared to mirror this, with no active sites found during this period. However subsequent research has since identified a number of coastal sites which were occupied during this event, such as Akab (Mery *et al.* 2008; Beech 2010). Therefore although climate deteriorated it not result in a complete abandonment of the area, neither did it result in an intensification of coastal resource exploitation, although this did continue.

3.2 Chapter Summary

In this chapter it has not been possible to demonstrate that climate played a role in the emergence of shell mounds around the Arabian Peninsula. However the Farasan Island sites coincide with climate aridification, suggesting a possible cause for intensification in this instance. At present this is only a tentative link given that they also closely coincide with the stabilisation in sea level. Further work is needed to resolve these issues, and to determine whether these sites represent a social and economic response to climate and/or sea level change.

Further around the Arabian Peninsula and adjacent coastlines there is no clear correlation between climate and site initiation. However there are a greater number of sites present once sea level had stabilised. Coastal

instability has resulted in many earlier sites being preserved; suggesting that the greater number of sites after 6000BP is an artefact of preservation.

Chapter 4

Site Distribution and Size – A Sign of Intensification?

4. Site Distribution and Size – A Sign of Intensification?

4.1 Introduction

The distribution of sites at both a local and regional scale is crucial to our understanding of prehistoric coastal exploitation in the region and whether they represent an intensification or more prolonged continuous activity. This is particularly relevant given the extremely high number and density of sites on the islands, compared not only to the region but globally. By better understanding the distribution we can begin to reconstruct the patterns of exploitation, interactions between sites, and relationship to the environment and change through evidence such as palaeoshorelines. Further understanding will be derived from dating the sites to establish timing in relation to other sites and environmental change; dating will be explored in a subsequent chapter.

The first aim of the thesis is to determine the distribution of shell bearing sites across the Farasan Islands. The first objective associated with this is to map the location of shell midden sites across the islands; tied into this is the location of the palaeoshorelines and their relationships to the sites. The second aim: to sample selected sites for dating and to determine internal composition/structure will be explored in subsequent chapters.

The distribution of sites will be assessed in a number of ways. The presence of a large number of sites has already been demonstrated by the 2006 Southern Red Sea field season (Bailey *et al.* 2007a). This will provide useful data on which to build, including a wealth of GPS locations for known sites. Before field work for this thesis commenced a number of lines of evidence were used to guide field work and assess the extent and relationships of the sites. These methods include satellite image interpretation (SII) and the creation of a digital terrain model (DTM) and false colour composite images (FCC). These lines of evidence were drawn together in a geographic information system (GIS), to which subsequent data derived from field work was and can be added. Interpretation derived from these combined lines of evidence will be used

4. Site Distribution and Size – A Sign of Intensification?

to help answer the questions which are central to this work. Finally surveying sites allowed both their size and surface composition to be recorded where resources allowed. This would allow a basic calculation of the volume of the sites and amount of shell present.

4.2 Methods

The methods mentioned above can be divided into two groups, those which are part of a desk based assessment, and those which form part of field based survey. The desk based assessment includes reviewing existing site distribution data for the islands and the creation, interpretation and use of SII, DTM, FCC and GIS. Field survey includes mapping palaeoshorelines, surveying and recording sites. Site sampling was also undertaken during survey, but this will be reported in subsequent sections; likewise recording sites involves an assessment of their size and composition, which will also be reported in later chapters.

Data collected in 2006 by the Southern Red Sea Project (Bailey *et al.* 2007a, 2007b), as well as data from other projects and surveys such as that of Zarins *et al.* (1980) and a PhD thesis (Bantan 1999) demonstrated the widespread nature of sites, and also salt tectonics across the archipelago. The Southern Red Sea project recorded up to 1000 GPS points recording archaeological sites, which needed to be loaded onto the GIS and interpreted. These files were in varying formats, and required processing in order to make all of these formats compatible.

The GIS database was created using ESRI ArcGIS software, combining this data with Landsat satellite images from the Global Land Cover Facility (University of Maryland). The DTM was created and applied to the database using NASA SRTM (Shuttle Radar Topography Mission) data which supplies rectified topographic heights to 90m resolution. Finally False Colour Composite images of the study area were created; this was done by taking the Landsat images and combining different bands. Ground truthing during the field survey would help to verify these results

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insuring accurate interpretation. The final research tool used for the desk based assessment was interpreting satellite images, primarily sourced from Google Earth.

To facilitate the both the survey and the archiving of data, the islands were divided up into a number of research areas (Figure 16), with divisions being made along obvious geographical features and boundaries in the landscape. Where this was not possible arbitrary boundaries were established; work was carried out by the area within the islands. Each area has been given a two character code, relating to its geographical name, or a significant place in the research area. There are ten research areas in total, two on Saqid Island, six on Farasan Island, and two on Qumah Island. These are Saqid North (SN), Saqid South (SS), Northwest Farasan (NF), Khur Maadi (KM), Janaba West (JW), Janaba East (JE), Gandeel Peninsula (GP), Farasan East (FE), Qumah Island (QI) and Qumah Bay (QB).

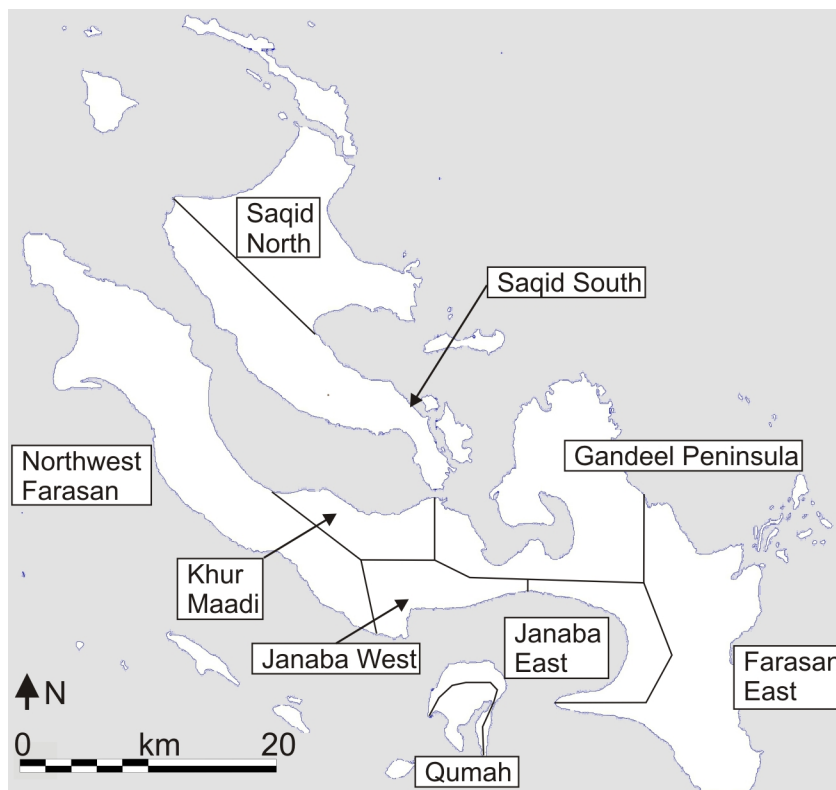


Figure 16: Research areas on the Farasan Islands. Note that Qumah is divided up into two research areas – “Qumah Bay” to the south around the bay, and “Qumah Island” along the West, North and East coastlines.

4. Site Distribution and Size – A Sign of Intensification?

The field survey built on the 2006 exploratory work (Bailey *et al.* 2007a, 2007b) which had recorded numerous shell sites across the islands, and documented many of these with GPS points. However the aim of the 2006 survey was to survey the islands for archaeological potential rather than investigating the shell mounds. A key factor in this is that the shell mounds had not previously been recognised as anthropogenic before this time. The locations of groups of mounds were recorded, however single GPS points were allocated to groups of mounds, and no data was collected on site size and composition. This data provided an excellent foundation on which to build, having located key concentrations of shell sites.

Several techniques were used to carry out the survey. A specific research area would be targeted and survey carried out over the course of several days. Some areas were more accessible than others, although all required four wheel drive vehicles to access (with the exception of Qumah which also required a boat). Survey strategies were chosen to best fit the conditions, although for consistency these were kept as similar as possible. Each survey utilised a four wheel drive vehicle, GPS, field notepad, satellite images and DTM; using these in conjunction reduced the possibility of missing smaller isolated sites. When time was short and the priority of the research area deemed low only the GPS position of the sites were recorded. If more time was available and the research area was deemed a priority (most likely because it was at risk of destruction) dimensions (length, breadth and height using basic geometry) and surface composition were also recorded; finally if the site was deemed more interesting, a three dimensional GPS path would be recorded over a shell mound, using a differential GPS in a backpack. This technique was often used if the site in question needed to be surveyed and was a composite site composed of a number of merged shell mounds. These were hard to measure accurately in the short time available; using the differential GPS meant the site could be surveyed to within 10cm accuracy in a relatively short space of time.

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The coastline which needed to be surveyed is extensive; the central island of Farasan Al-Kabir has over 200km of coastline alone. Saqid, the second largest island has over 80km of coastline; this island is accessible from Farasan by a bridge. An additional >25km of coastline on the island of Qumah took the total length of shoreline which needed to be surveyed to over 300km. However, the desk based assessment revealed that many shell mound sites were found inland, some over 2km from the modern coastlines. This demanded a flexible approach to surveying, where attention was not focused solely on the modern coastline.

As is evident in Figure 17, in many instances the shell sites were visible on the satellite images, allowing the vehicle to be directed to them, and the sites surveyed. Having surveyed the sites, they could then be ticked off on the satellite image to show that they had been surveyed. Adding an extra layer security, a map could be called up on the GPS set, showing GPS points allocated – and thus which sites had been surveyed. However, in cases such as that shown Figure 14 where satellite images are unable to reveal the location of shell bearing sites, the areas had to be systematically surveyed with the aid of the satellite images, DTM and False Colour Composites; in some cases it was necessary to survey in transects to ensure full coverage. For areas such as Qumah Bay the only possible way was to undertake the survey by foot due to the rugged conditions.

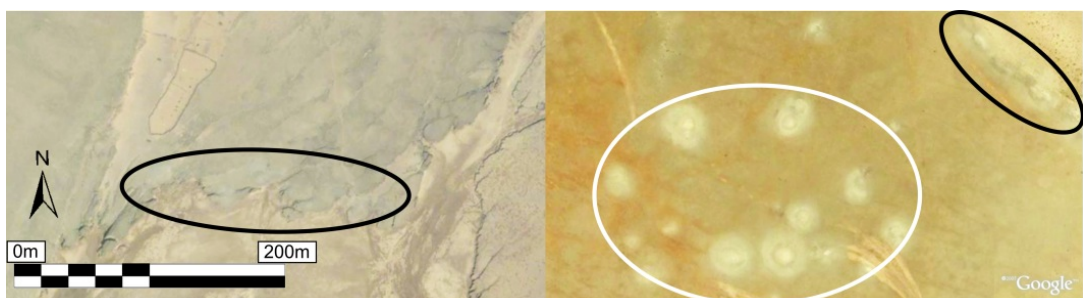


Figure 17: Image to the left shows darker coral terrace with darker shell mounds on it – circled in black; image to right shows thin veneer of sediment in an in-filled bay. Lighter shell mounds are circled in white, darker are circled in black.

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Fortunately in most cases such as these there were well defined palaeocoastlines, along which the majority of sites were situated thus negating the need to traverse the landscape in transects. This allowed comprehensive surveying of the target areas. These techniques allowed the efficient surveying to be carried out, maximising the use time in the field. Despite this large areas of the island are still waiting to be surveyed – a product of the large size of the survey areas, short field season, and other field work which needed to be carried out.

Where dimensions of the site had been recorded this would allow for a calculation of the volume of the site and the amount of shell it contained. This was achieved by using the truncated cone model (eg Sorant and Shenkel 1984) where:

$$\text{Volume} = \text{height}/3 [\text{Area1} + \text{Area2} + \sqrt{(\text{Area1} \text{ Area2})}]$$

and:

$$\text{Area} = \frac{1}{2} \text{height} \times (\text{Base 1} + \text{Base 2})$$

This calculation works well for shell mounds which are symmetrical truncated cones, however a number of sites were either elongated or composite mounds, which complicated calculations. For elongated mounds the formula could easily be adjusted to allow for half a truncated cone at each end of a trapezoid. However it was more complicated for composite mounds.

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The weight of material in a site could also be estimated, since the density of various combinations of shells and sediment were found to be similar, at around 2kg per 2000 cubic centimetres material, or scaled up 1000kg per cubic meter.

Although the survey was primarily tasked with finding shell sites, other sites of archaeological interest were also noted. This took extra time but was deemed necessary considering the absence of data covering the archaeological record of the islands. These results are not published here, but will appear in the yearly fieldwork reports published in *Atlatl the Saudi Arabian Archaeological Journal*.

4.2.1 Data review

The 2006 fieldwork data was predominantly composed of GPS locations with limited information on sites; therefore this data was most useful for informing where groups of shell middens were located on the islands. This was particularly helpful when combined with a map of the areas visited by the 2006 field team (Figure 18), since any areas visited, but without data were unlikely to contain sites.

The data from the 2006 survey revealed the following locations (Figure 18), although actual data on the sites (such as number of sites, type of sites, and size of sites) was lacking. However this data would prove useful and insightful on where to look for shell middens. This could then be overlain onto the DTM and false colour composite satellite images to inform further on site location and past landscape change. In addition this data could also be used to focus satellite image interpretation, informing on which areas shell middens might be located.

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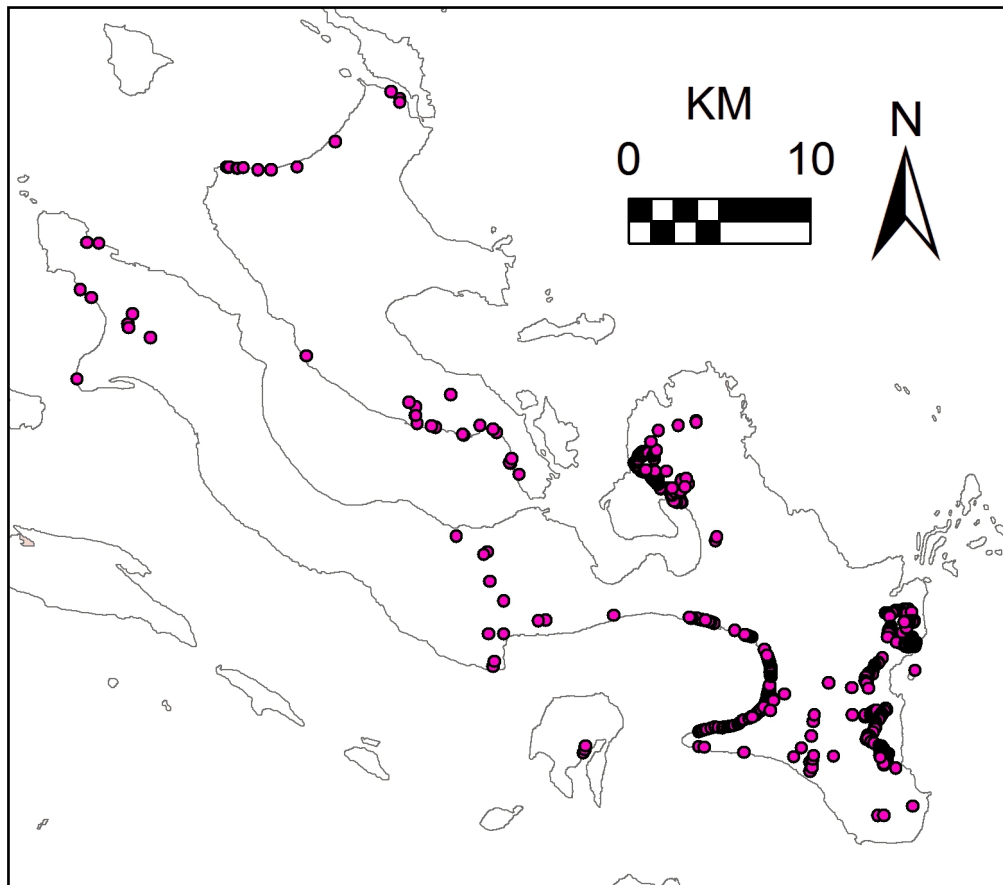


Figure 18: Sites located during 2006 survey.

4.2.2 Satellite Image Interpretation

The next stage of investigation was satellite image interpretation; areas visited by the 2006 survey were located on satellite images. The most useful source of high resolution images is Google Earth, which provides images of the islands with resolution of up to 0.5m. In this way the spectral signature of known shell mounds could be assessed, and recorded. Many shell mound sites are visible on the Google Earth satellite images, contributing to their visibility is the lack of vegetation, and arid environment where sediment erosion and deposition is restricted to irregular precipitation events and aeolian transport. Low modern population densities and limited development have ensured that sites are not destroyed to the same extent as has happened in many other areas of the world.

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In the majority of cases these appear as white areas on the darker background; field assessment showed this to be a result of lighter coloured shells (such as *S. fasciatus*), against the darker background of uplifted fossil coral terraces (Figure 14). These fossil terraces are predominant over the islands, and have been uplifted by salt tectonics. In places the shell mounds have a darker colour, and are more indistinguishable from the coral bedrock. In these cases it became apparent that the predominant shellfish species on the mounds were *Chama reflexa* and *Spondylus marisrubri* which have a much darker shell than the lighter *S. fasciatus*. Therefore although satellite images are a useful guide to shell site distributions, they cannot be relied on as definitive evidence. However used in combination with a careful field survey, DTM, FCC and SII they proved to be extremely useful and helped in identifying concentrations of shell mounds which would be targeted during the survey, many of which were previously unknown.

A recent paper by Kennedy and Bishop (2011) has highlighted the use of this technique for locating archaeological features in other parts of Saudi Arabia using similar principles to those used in this investigation.

A total of 1773 new shell midden sites which have not been visited during field survey have been located using this technique (Figure 19). This is in addition to the many sites located on satellite images and visited during survey.

4. Site Distribution and Size – A Sign of Intensification?

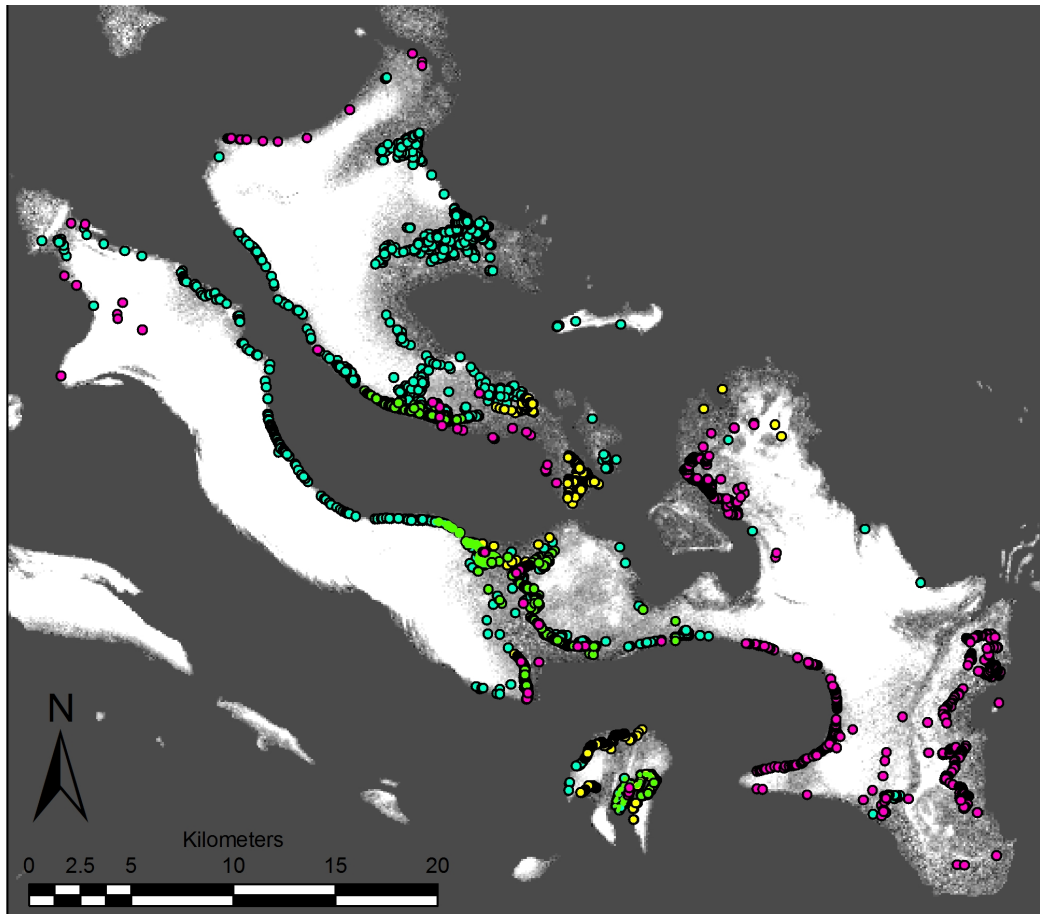


Figure 19: Farasan Island shell site locations - sites located by satellite image interpretation in blue. Sites located by survey (and year surveyed) – purple 2006, green 2008 and yellow 2009.

4.2.3 Digital Terrain Model

The DTM was constructed using NASA SRTM (Shuttle Radar Topography Mission) data combined with Landsat Images (Figure 20). SRTM data was recorded at 90m² (sometimes 30m² but unfortunately not in this region) resolution and is freely available for research purposes. It has since been superseded by the Global Digital Terrain Model (GDEM), although claimed to have higher resolution, this is often unattainable, particularly for more remote areas where the data is yet to be rectified. For this reason the older SRTM data was used in this study.

4. Site Distribution and Size – A Sign of Intensification?

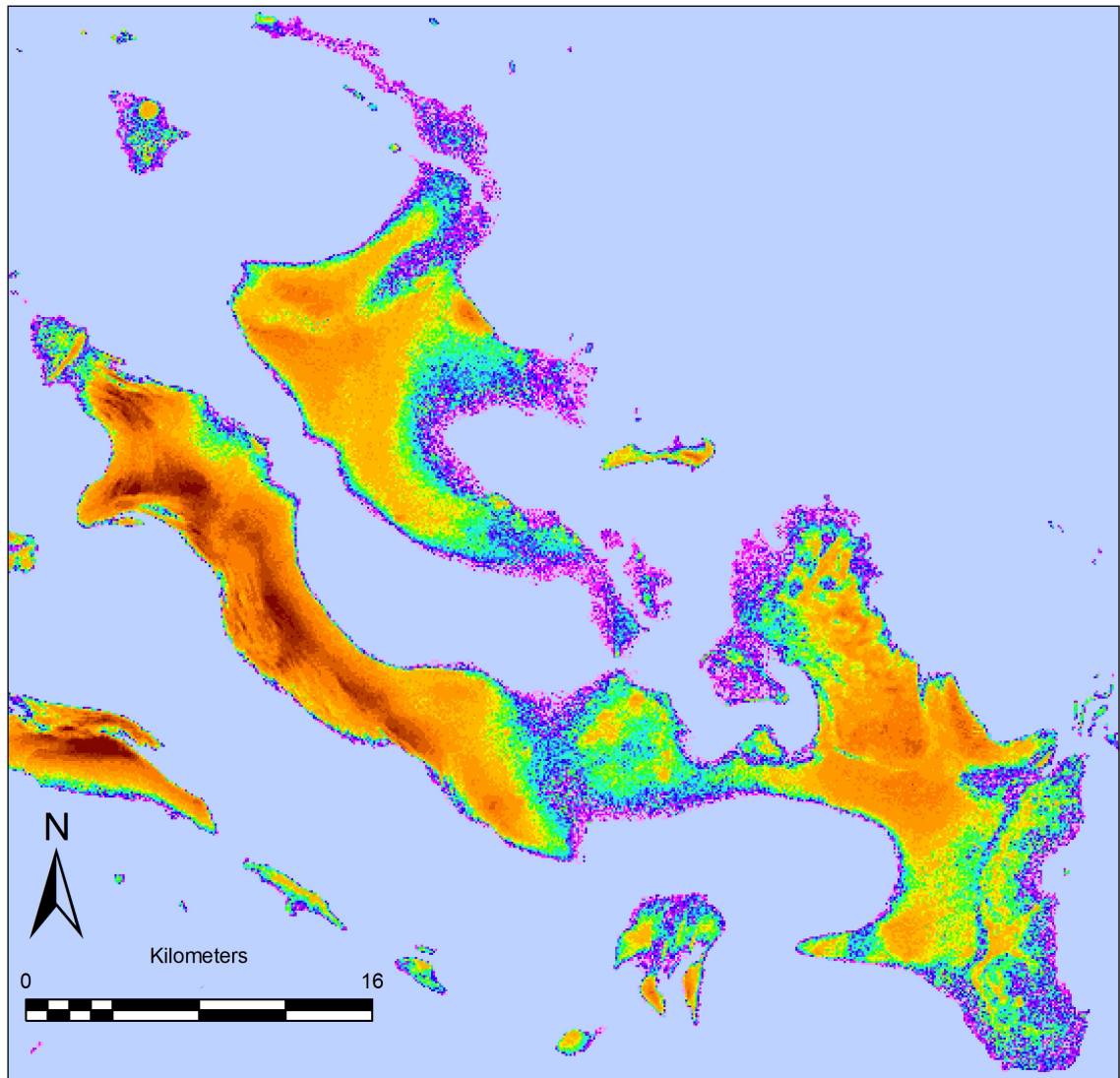


Figure 20: Digital Terrain Model (DTM) of the islands.

The 90m² resolution provides a good representation of the islands, and their palaeoshorelines. The islands have a relatively low topography with a maximum elevation of c.70m and mean elevation of 10-20m above sea level (ASL), meaning that the data needs to be classified in order to show features clearly. This is relatively easy to do by assigning different colours to specific elevations. The result is useful for understanding the landscape and any changes that may have impacted upon it; in addition to this site distribution can be overlain to highlight any patterns or associations.

Features such as bays and channels can clearly be seen extending from the coastline inland, showing a continuation of the topography. This can

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potentially show palaeoshorelines and areas where uplifting or in-filling may have occurred. However there is no way to verify these features or their age from the DTM, therefore this method must be used in conjunction with others, such as field survey.

The DTM in Figure 20 shows the accentuated topography of the islands after classification of the data. As mentioned, it is best to interpret this data in conjunction with other lines of evidence; extracts of the DTM will be included with each research area results section.

4.2.4 False Colour Composite Satellite Images

The FCC images were created using Landsat satellite images retrieved from the University of Maryland's Global Land Cover Facility which provides free resources for research. Landsat multispectral data was used, which has up to eight bands (wavelengths) available. Three bands are selected and assigned Blue, Green and Red; this means that the wavelengths of each shown in the image will be displayed in the chosen colour. Using this method it is possible to create maps using "invisible" wavelengths such as infrared; this allows features that are distinguishable in invisible wavelengths to be shown in visible colours.

The Farasan Islands are covered by limited vegetation, meaning that highlighting geology as opposed to vegetation would yield the best results. For this reason bands 4, 5 and 7 were selected and processed using Adobe Photoshop (King, pers. comms. 2008). It was only necessary to distinguish between rock and depositional sediments, therefore only basic processing was necessary in order to highlight these distinctions. In addition it was possible to distinguish two types of depositional unit: fine sand and coarse sand or thin sand cover over bedrock. Unfortunately it was not possible to tell the difference between coarse sands and a thin sand cover over bedrock due to the similarities in spectral signature. Figure 21 is just one example of a number of false colour composite images constructed and interpreted for this

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investigation. These show a slight variation from those of Bantan (1999), in which determining the underlying geology was the concern.

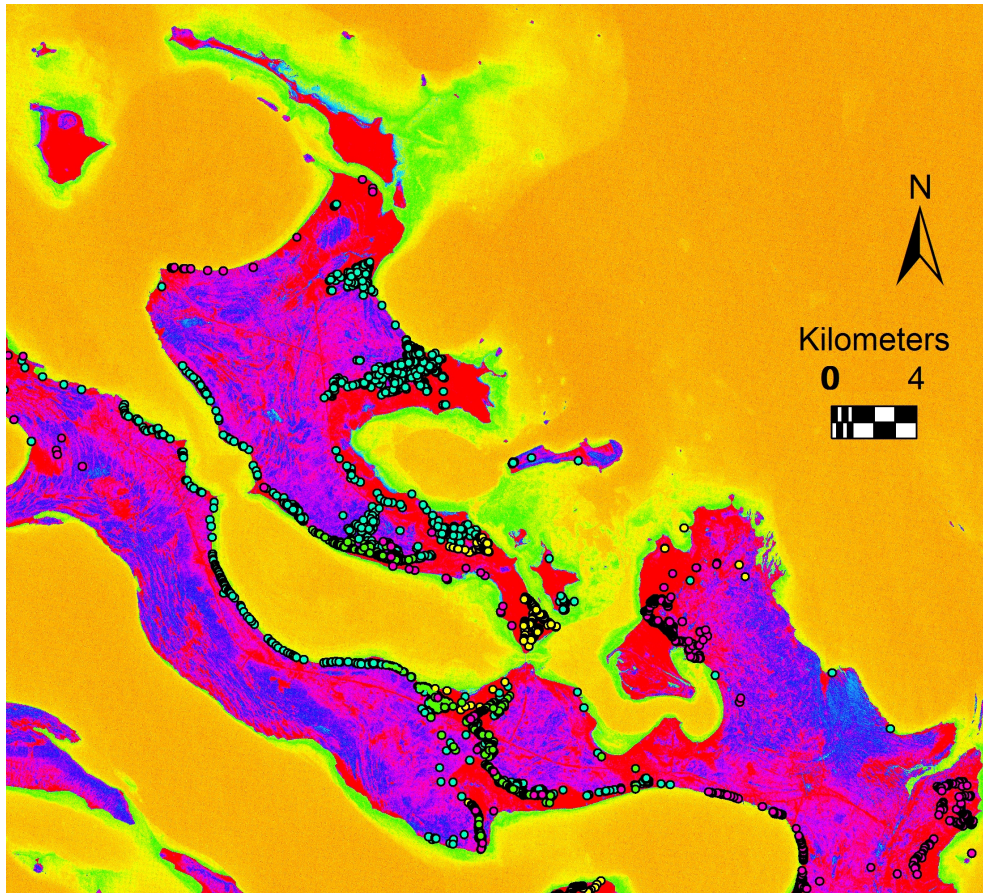


Figure 21: Unsupervised classification of a false colour composite satellite image of the Farasan Islands which has not been cleaned. Note that red areas are predominantly depositional sediments, but not exclusively, therefore a number of processed bands must be combined.

Figure 22 is a cleaned classification of the Farasan Islands which has had unwanted signals removed. Sand cover (yellow), coarse/thin sand veneer (green) and fossil coral terrace (blue/green) are the only signals retained in this image. These show where wadi basins or marine transgression have deposited sand inland. Given their small size, low relief and limited precipitation, the islands have few wadis. Wadis where any depth of sediment has accumulated are rarer still. Almost all of the depositional features on the map are along coastal locations or low basins which extend inland. However this method gives no indication of the age of deposits and must be used in conjunction with other methods such as field survey.

4. Site Distribution and Size – A Sign of Intensification?

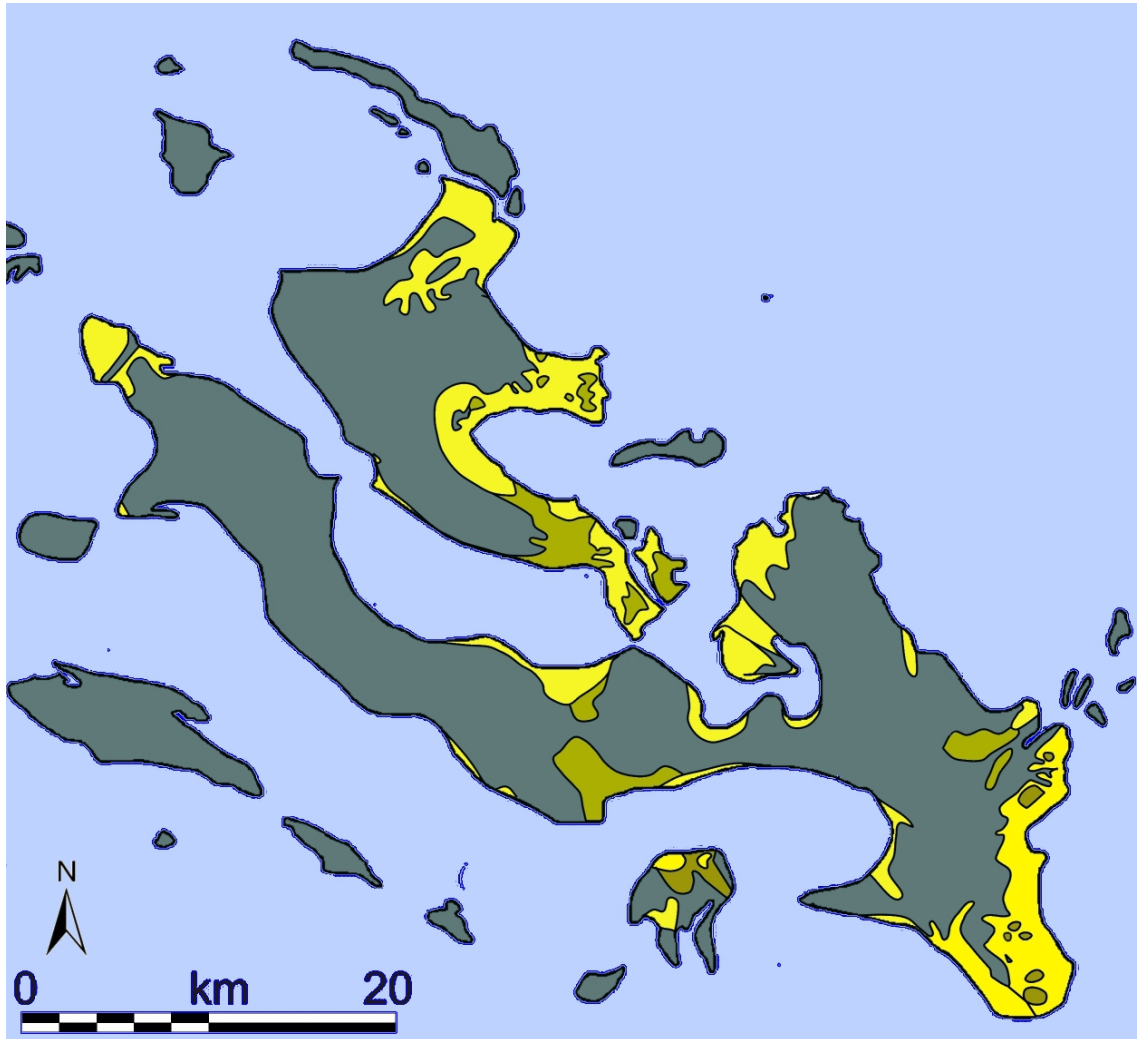


Figure 22: False colour composite of the Farasan Islands, showing sand cover (yellow) and coarse sand cover/sand veneer (olive).

The location of sites across the main islands corresponds well with the areas of depositional material on the cleaned false colour image. In places the deposits of sand extend beyond the palaeoshorelines, perhaps indicating older phases of inundation.

4.3 Results

The results will be presented for each research area as defined earlier in this chapter. A brief general overview of the survey results for the islands will be provided, allowing each research area to be put into context with the rest of the archipelago.

4. Site Distribution and Size – A Sign of Intensification?

To date 2811 shell middens have been located on the Farasan Islands, both as a result of field survey and satellite image interpretation. Sites are concentrated on the three islands of Farasan, Saqid and Qumah, and in most cases follow the palaeoshorelines of the period in which they formed. The majority of sites are located 3-4m above present sea level; however there are some which are up to 15m – the result of them being situated at the top of high cliffs. Sites are located both along bays and open shoreline, with the majority of sites being situated onshore adjacent to shallow subtidal shelves. Uplifting and deposition has resulted in the sea retreating in many areas, in some cases this is up to several kilometres. The general trend for sites to be located 3-4m above present sea level suggests that the vast majority of sites will have formed during the same phase of shell mound building activity when relative sea level on the islands was higher. However the fact that sites in some areas are on palaeoshorelines and are higher than others suggests either localised uplift or different phases of sea level and shell midden accumulation. However some palaeoshorelines (and sites located on top of these) were found to be warped, suggesting that local tectonics were affecting the landscape, rather than the palaeoshorelines dating to different stages of relative sea level.

Site GPS locations have been combined with satellite images (both Google Earth and Landsat) in order to allow better interpretation of the sites, and their locations within the broader landscape. Extracts of these are included in the following results.

A number of surface finds were collected on the survey – predominantly lithics, and a number of quern stones. These form a tiny component of the total finds, and are very rare. However they are very important in our understanding of the sites. Although almost all were found unstratified as surface finds, they were often found on or close to shell mounds. It is bold to associate unstratified finds such as these with the sites they are closest to; however there is no other typological find available. They were found in greater concentrations near and on shell sites than in other

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areas; whether or not this is a result of the survey strategy is debatable and must be considered. Inland survey was undertaken as part of a different branch of the project, tasked with locating a much earlier human presence during the Palaeolithic. The density of finds (including those typologically similar to those found in the vicinity of the shell middens) was consistently much lower than at the shell mounds and their associated (palaeo)coastlines.

The most common lithics found on the survey were composed of basalt (Figure 23). The majority of these were blanks or debitage. However scrapers, points and blades were also found.



Figure 23: An example of a surface find. A basalt lithic found on a shell mound in Qumah Bay. (Photo N. Al Shaikh).

Only two obsidian artefacts were recovered, these being an arrowhead and a point. Several polished green stone axes were recovered, and a handful of green stone flakes. Several worked shell flakes were recovered, thought to be of *Tridacna*. Several quern stones were recovered, with the most common material being granite; however a large set of quern stones made of river pebbles were recovered from unstratified deposits in Southern Saqid.

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Several pieces of worked basalt were found on the surface near the sites JE0004 and JE0002. This material is found in low concentrations across the islands. A pebble hammer was also found within JE0004 during excavation – one of the few tools to be found in context. Similar finds have been found on the mainland associated with Neolithic shell middens (Zarins and Al-Badr 1985).

Unworked fossil coral (the local bedrock material) was also found in large concentrations on shell middens. These consisted of portable blocks in a variety of shapes and sizes (c.5-20cm diameter) with no obvious signs of having been worked. These perhaps represent implements used in the processing of shellfish, or maybe to weigh down tents/windbreaks.

A total of 767 shell mounds were systematically recorded in 2008, 467 by a single GPS point (accurate to 10–30 cm) and 300 by differential GPS survey. In 2009 a further 271 shell mounds were surveyed bringing the total number of known shell-bearing sites to 1038. This is supplemented by 1773 shell mounds located on satellite images, raising the total number of sites to 2811. These are distributed across the islands, and have been broken down by research area in Table 3 below.

Area	Code	Number
Janaba East	JE	144
Janaba West	JW	373
Khur Maadi	KM	230
Qumah	QB	227
Northwest Farasan	NF	131
East Farasan	EF	254
Gandeel Peninsula	GP	154
Saqid North	SN	602
Saqid South	SS	696
Total	--	2811

Table 3: Break down of number of shell midden sites per research area.

4. Site Distribution and Size – A Sign of Intensification?

4.3.1 Janaba East – JE

The Janaba East research area is delimited by the headland of the Shida Peninsula to the south and in-filled sediments of Janaba Bay West in the west. It is distinguished by a cliff on which the shell middens are located (Figure 24); the cliff marks the modern coastline along the Shida Peninsula and to the north between the harbour and Janaba Bay West. In the central area it is a cliff located at the rear of a sandy beach.



Figure 24: View east along Janaba Bay East showing sandy beaches in background and cliffs in foreground. Shell mounds are visible along the top of the cliff (photo H. Robson).

The survey of Janaba Bay East was undertaken in 2006, 2008 and revisited in 2009. One hundred and twenty nine shell mounds were recorded in an almost unbroken arc around the bay. The entire eastern extent of the Janaba Bay palaeoshoreline is dominated by a cliff with an average height of 2-3m. The present day shoreline is more variable, to the west of the point marked “A” on Figure 21 there is a two to three meter cliff which descends into the sea. In places there are thin strips of sand at the foot of this, however these are few. Points “A” to “B” mark where there is an extensive beach in front of the cliff, which is now

4. Site Distribution and Size – A Sign of Intensification?

located inland. After point “B” the palaeoshoreline joins the modern shore and is manifest as a low cliff. The beach is composed of sand, and these deposits extend back as far as the cliff line. Depositional sediments between the modern and palaeo-shorelines can be seen on the false colour composite satellite image of the bay (Figure 26).

Surveying in 2006 and 2008 showed 144 shell mound sites following the cliff line. Figure 25 shows the line of shell mounds hugging the coast, except between points “A” and “B” where they follow the cliff inland. The sites range in size from scatters to mounds up to 2m in height, however the majority are in the 1-1.5m range. In places they spill over the cliff onto the foreshore. Key species present on the surface of sites are *S. fasciatus*, *C. reflexa*, *S. marisrubri*, *P. trapezium* and *C. ramosus*.

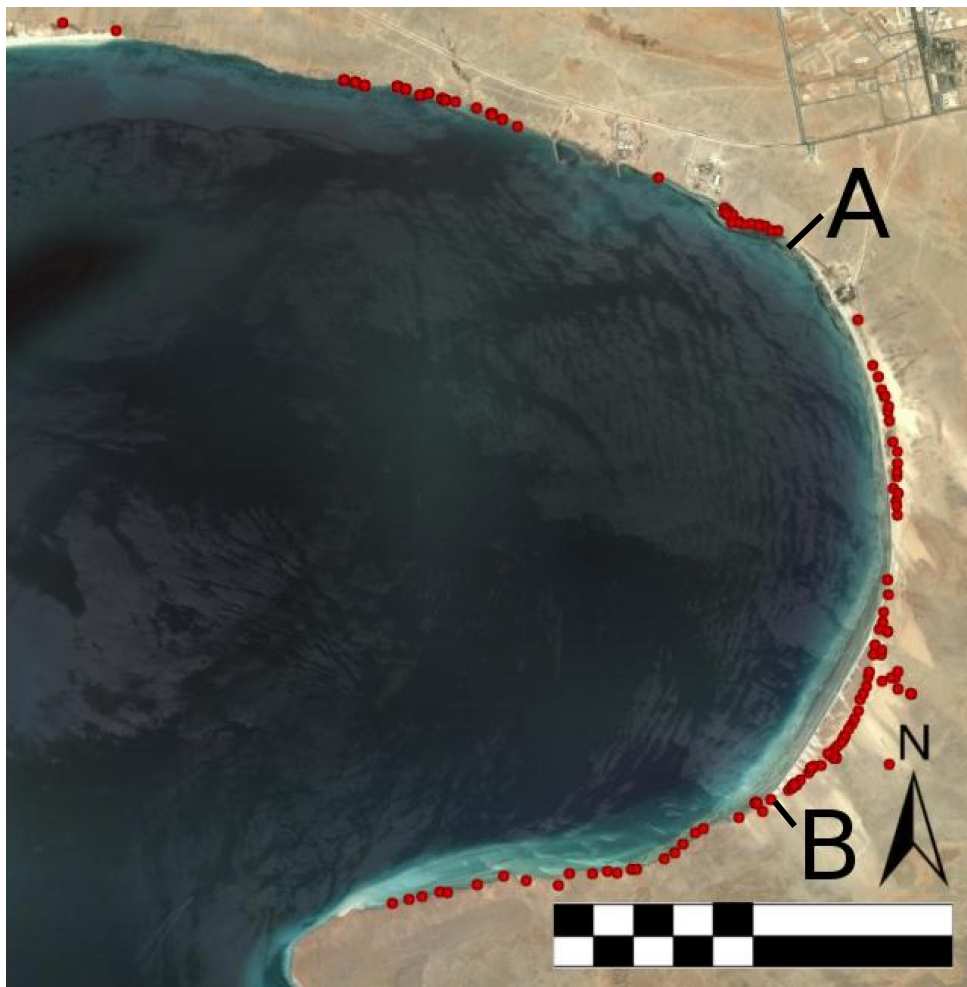


Figure 25: Janaba Bay East – The shoreline is marked by a cliff, except between points “A” and “B” where the cliff is now located inland, and the shore is dominated by a beach. Red dots mark shell sites.

4. Site Distribution and Size – A Sign of Intensification?

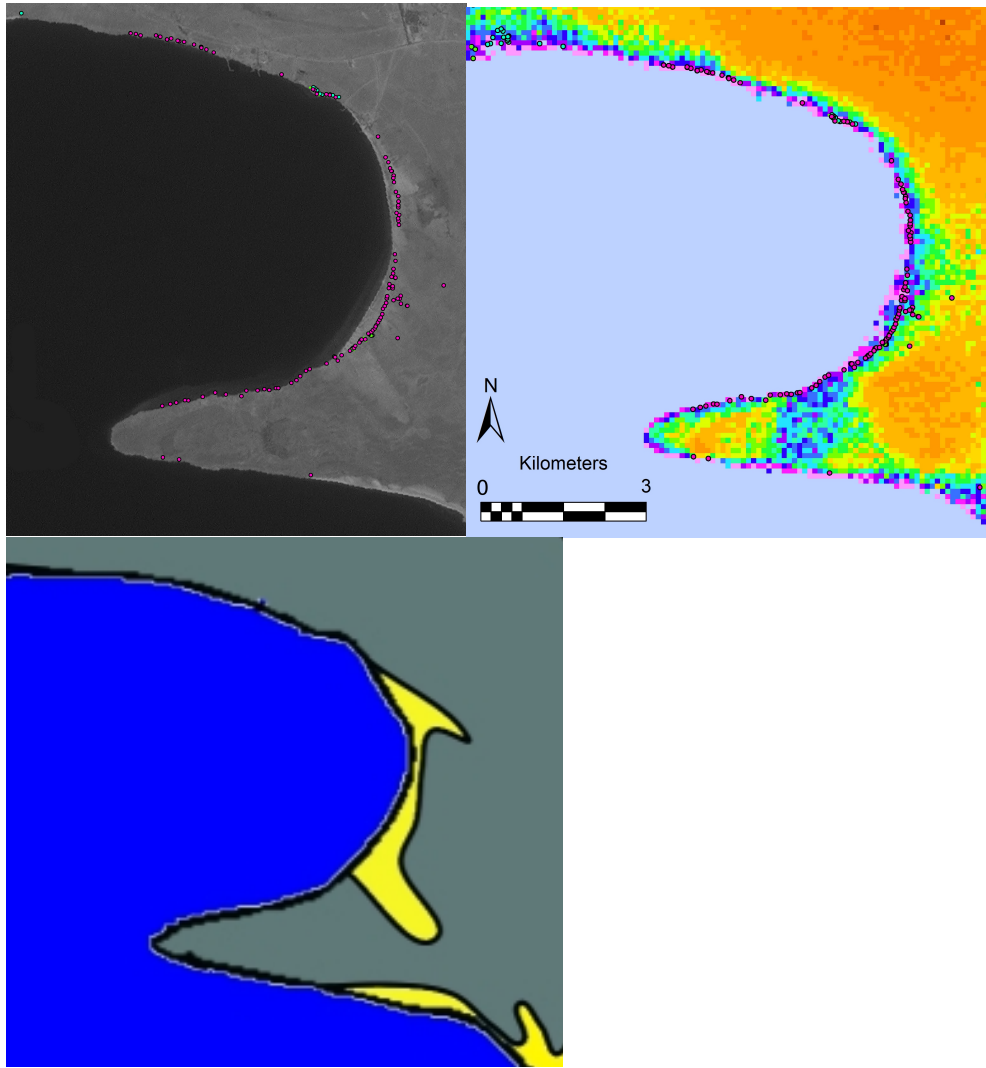


Figure 26: Janaba East, from left to right, satellite image, DTM, FCC.

The distribution of sites is predominantly linear, with the exceptions of a small group of seven sites set back from the palaeoshoreline in the centre of the bay. This pattern of distribution is common across the islands, where a small group of sites is located further inland from the main distribution along the coast. These sites are also slightly higher than those on the palaeo-cliff-line, with a mean basal height of around 7m (range 6-8m), as opposed to 2-3m along the cliff-line. The FCC image suggests that this area has depositional sediments, however it is not currently known if the sites in this area were deliberately sited inland, or whether there was a small inlet which has been uplifted.

The mean basal height of the sites around the bay is 2-3m ASL, this is consistent around the bay at sites both on the palaeoshoreline and

4. Site Distribution and Size – A Sign of Intensification?

modern shorelines, suggesting that sedimentation rather than tectonics may have been responsible for the movement in shoreline. However the wave cut notch at the base of the cliff is still at sea level at site JE0004, but is uplifted and exposed at the other end of the bay to the south east. A number of sites on this uplifted cliff have a basal height of 6-8m. This suggests that some local warping has occurred in the east of the bay - whilst further around the bay near to site JE0004 there is more stability. This could be an underlying factor in the sedimentation that has occurred in the eastern end of the bay. Uplifting would have exposed the shallow subtidal shelf above sea level. This would have made the shelf more suitable for deposition, since sediment deposited by high tides would not be washed away by currents. The DTM shows the difference in height between the sandy deposits on the shore and the cliff line behind. The DTM and FCC clearly highlight the change which has occurred in the east of the bay, where low topography and depositional sediments show where the sea has retreated. Compared to many other areas of the islands this change is more restricted, and along some sections of coastline is negligible.

4.3.2 Janaba West – JW

The western half of Janaba bay is described as a separate research area. This decision was based on the coastal setting, which changes from a small cliff into a sediment filled bay. The sediment lies in front of a palaeoshoreline marked in many places by a raised beach and shell middens. The start of the sedimentation marks the start of Janaba Bay West – which is a wide in-filled and uplifted palaeo-bay extending c.9km across at the widest point, narrowing to c.1.5km in the interior. The evidence available (satellite images; site locations; false colour composites; and DTM) suggests that this bay was at one time a channel that extended right the way across the island joining up with the Khur Maadi Bay to form a continuous body of water (Figure 27).

4. Site Distribution and Size – A Sign of Intensification?

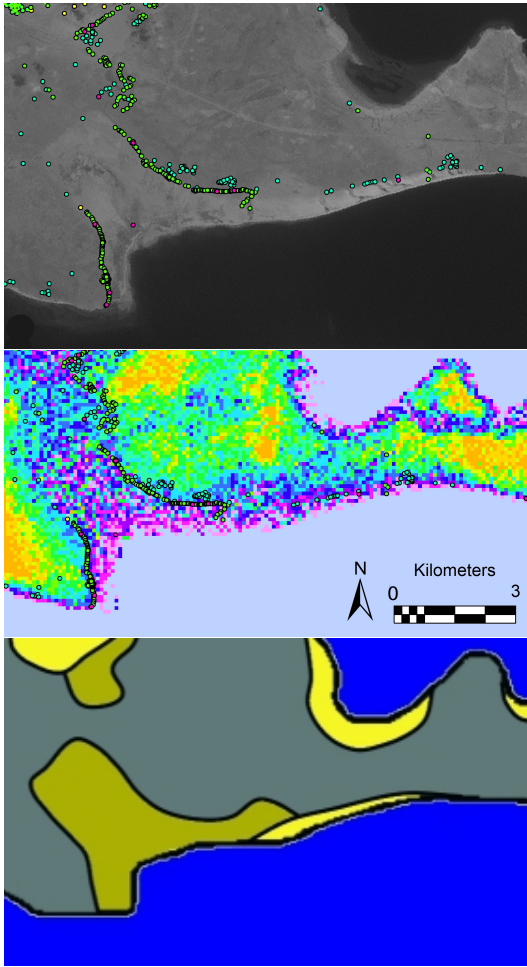


Figure 27: Janaba West, left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

There are 289 sites along this stretch of palaeoshoreline; 109 on the west bank over c.7.5km, and 178 on the east bank along c.12km. On the eastbank of the bay the palaeocoastline is shadowed by a near unbroken line of shell sites. As the bay turns inland, the distribution of shell sites changes from a linear distribution to a more dispersed pattern within a wider corridor. The transition is marked by the disappearance of any discernable palaeoshoreline features and replaced by a gradual transition from depositional sediments to exposed fossil coral bedrock. The line of shell sites continues inland linking up with the eastern palaeocoastline of the Khur Maadi bay, in a near continuous line. In several locations there are small clusters of shell sites set back from the main distribution of sites. The DTM suggests that these may have been inlets, however further research is needed to clarify this.

4. Site Distribution and Size – A Sign of Intensification?

The western side of the palaeobay is dominated by a high cliff-line, topped by a linear row of large shell mounds (Figure 28). Here too there is a concentration of smaller sites set slightly further inland from the main distribution of sites. These seem to be associated with low points in the landscape, perhaps an ephemeral wadi. As the palaeobay approaches the centre of the island there are fewer shell sites along the western edge, and the palaeoshoreline features become less distinguishable, making it hard to estimate the extent of the bay.



Figure 28: JW looking north (top – H. Robson) and west (bottom – M. Williams).

4. Site Distribution and Size – A Sign of Intensification?

The distribution of shell sites along the western side of the bay extends for 2.2km from the modern shoreline inland along the palaeobay. A cliff extends for 1.9km, declining in size from the modern shoreline inland before petering out (Figure 29). The shell sites persist for another 0.3km along the palaeocoastline; their size decreases further inland, getting progressively smaller until the group ends in a series of large scatters. Over the next 4.5km (between the last large scatter and the KM group) there are only a handful of small scatters (nine in total – five of these a linearly distributed, hinting at a palaeocoastline) before the Khur Maadi group begins.



Figure 29: JW looking south, showing decrease in size of sites into the foreground (photo H. Robson).

The largest shell mounds of the Janaba West group are located along the western cliff line. The largest of these sites are in excess of 4m high, and 40m across, some are topped by blocks of coral, which presumably formed the base of structures (Figure 30). These coral blocks are often associated with pottery, although the provenance of both is presently unknown. They are likely to post date than the shell mounds (since there

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was no pottery on any of the other sites). It seems plausible that these represent a reuse of the sites; most likely because of their prominent position in the landscape and their physical size attracting reuse.



Figure 30: A large mound (upper), and a coral block structure on top of a

4. Site Distribution and Size – A Sign of Intensification?

mound (lower). Both photos taken looking southeast, showing former bay in background (Photos H. Robson).

The shell sites on the eastern side of the bay are much more restricted in size, with the largest being up to 1.5m in height. However there are a number of groups of shell middens, set back slightly inland away from the main distribution of shell sites along the palaeocoastline. There are three examples of this along this section of palaeocoastline; further investigation is needed to assess whether this is a result of small inlets punctuating the palaeoshoreline, or whether it represents a difference in site selection preference of the fisher-gatherers.

The interior of the palaeobay is dominated by a thin covering of deposited sand. In places a hard rock is visible (Figure 27). It is not clear whether this is bedrock – ie coral terrace – or farrush, a hard concretion which forms in the intertidal zone in calcareous sandy deposits. The height of this deposit is c.2m; combined with the evidence from the palaeoshoreline, which has clearly been uplifted exposing the base of the cliff-line higher than sea-level, it can be concluded with some confidence that this bay has been uplifted as well as in-filled

The average basal height of the sites on the western side of the palaeobay is 4-5m ASL. This rises from 3m in the south, close to the modern shoreline, to 6m further inland. This would strongly suggest uplifting towards the interior of the palaeobay. On the eastern side of the bay the average height of the linearly distributed sites closest to the modern shoreline is 3m, however further towards the interior of the bay this rises to 5 and then 6m. Again this would suggest that uplifting has occurred in the interior of the bay. At the furthest point inland, where the distribution becomes irregular, there is a greater rise to 7m, with a maximum height of 11m. Either these sites were purposefully located on higher ground, or the earth has been uplifted since their deposition. It is likely that the latter is the case, since the height of the sites would seem to suggest warping of the bay. This coincides with the uplift observed in the Khur Maadi bay and the presence of fault lines also in the Khur Maadi

4. Site Distribution and Size – A Sign of Intensification?

bay. The distribution of sites, together with the false colour composites strongly suggest the presence of a shallow subtidal channel extending across the island.

The western side of the bay was deemed highest priority for work, based on information from the Governor of the islands, who said that the area to the west of this location was due to be turned into an airport. There is a strong possibility that this area will soon be off limits or potentially destroyed.

Whilst undertaking the survey, a series of shell scatter sites were discovered which followed the line of a water course between the palaeoshoreline and the modern shore (Figure 31). These sites must be younger than those on the palaeoshoreline further inland, since they are closer to the shore, and would have been reworked on the open coastline had they been submerged. The sites are linearly distributed along the wadi and it is probable that these represent a continuation of the shell mound building activity, as the coastline retreated. The wadi would form a natural focus for activity, especially if there was rain and it was a source of fresh water. Vegetation would be denser in the wadi due to greater water availability, and this is the case today. Several stands of shrubs and trees exist in such locations today, showing the greater water potential for plant life.

These sites could be redeposited material from the main group of sites on the palaeoshoreline. There is evidence that the wadi has eroded into the c.1.5m high shell mounds, which flank the watercourse to the east and west. The eroded material would have been washed towards the present coastline, and redeposited forming layers looking very much like shell scatters. The evidence against this hypothesis and supporting an anthropogenic origin is in the shape, size and composition of the sites. The shell scatters are limited in nature and consistent in shape and size to other shell scatters across the islands. The composition is the strongest evidence, since the sites are composed of a single species – *C.*

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ramosus – and are located directly on the sandy substrate. These shells are not buried, half buried, or covered with sediment; they are simply sat on the surface as if dropped. Any sediment associated with them is more consistent with wind blown activity, where the sediment has consistent grain size and is not laminated with different grain sizes. Additional evidence is that the main group of sites are composed of a variety of species (including *S. fasciatus*, *C. reflexa*, *B. setigera*, *C. ramosus*, *P. trapezium* and *S. marisrubri*). Redeposition would most likely either have incorporated components of these mounds into the scatters, or sorted the material by size and weight. Neither of these scenarios was observed in the scatters.

These sites might therefore represent a continuation of shellfish gathering activities whilst changing conditions were altering the coastlines. It also shows that the shell beds were continuing to be viable resources, even if some shell beds may have been impacted by the changing conditions. The limited size of the scatters could be either an indication of a reduction in productivity of the shell beds, or a result of the coastal retreat – meaning sites had a shorter duration of use before they were stranded inland and abandoned. A final reason might be a change in exploitation strategy in response to the changing coastal conditions.

A walkover of the intertidal zone of the bay was carried out during the survey and revealed an abundance of live adult *C. ramosus* and *P. trapezium* on a fossil coral terrace substrate. This was enough to demonstrate that a productive ecosystem still flourishes; however it is unknown whether favourable conditions still exist for *S. fasciatus*, in the shallow subtidal shelf off shore.

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Figure 31: A deflated scatter located in between the modern and palaeo-shorelines. To left picture of stand of trees in the wadi located close to scatters; right shows shell scatter to the right hand side of the picture.

There is also evidence of more recent shellfish exploitation in the area. In the centre of the in-filled bay, set back roughly 10m from the high-tide mark there is a line of small steep sided shell mounds – c.0.5-1m in height. These are composed exclusively of the pearl oyster *Pinctada nigra* – which was exploited commercially on the islands until the middle of the twentieth century. It seems probable that these sites originate from this period.

4.3.3 Khur Maadi – KM

The Khur Maadi bay is a large palaeobay in the centre of Farasan Island, which has been uplifted and in-filled. It lies directly north of Janaba Bay West, and evidence suggests that they were once linked by a narrow, shallow subtidal channel. This was an important area for shell gathering activities: the bay is delimited by a high density of shell bearing sites (Figure 32).

There are 112 shell sites on the western side of the bay (Figure 32). To the north they are predominantly linearly distributed, following the palaeocoastline which is marked by a c.1-2m high cliff. The largest shell mounds of the group are located in this area. The most notable are two 3m high mounds (Figure 33) located next to one another, which are positioned in a prominent position at the mouth of the bay (KM1057 and KM1055). South of these two mounds, and into the interior of the

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palaeobay, the shell sites are widely dispersed with several clusters. The reason for these two distributions seems to be related to the coastal setting during the formation of the shell sites. Along the open coastline to the north, the palaeocoastline is marked by a cliff –indicating that the shoreline was stable for long enough for the cliff to form. It also suggests that the coastline remained stable during shell site accumulation and thus sites were located at the closest point to the shore, on top of the cliff. There is some variation to this, with small groups of sites set further back from the main distribution.

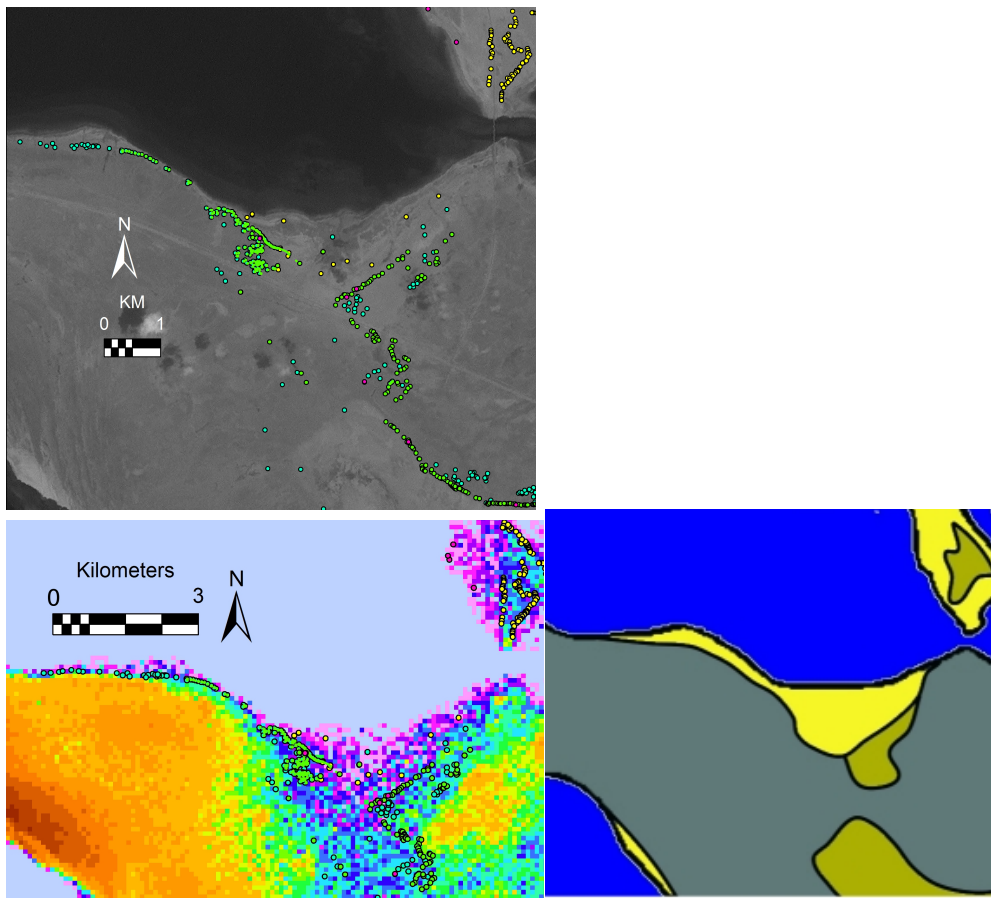


Figure 32: Khur Maadi, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

4. Site Distribution and Size – A Sign of Intensification?



Figure 33: Views over KM bay, showing the two largest sites of KM1057 and KM1055. Top looking northeast; centre looking southwest and bottom looking north (photos H. Robson).

The irregular distribution of sites to the south is not associated with a cliff, or any other discernable palaeoshoreline features. This would seem to

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indicate that the sites were situated in locations that were favourable during their formation. On a shallow sloping bay, the water level might reach different heights in different years, thus a site which was dry one year might not necessarily be dry the next. Therefore a new site would be located in the same area, but slightly higher up in the bay on a dry location. Re-use of some sites would soon result in material building up; in years of higher sea level these would form islands, and therefore become self selecting sites due to their proximity to the shell beds, and their dry nature.

Interestingly the cliff does not end at the two large shell mounds, but continues eastwards dipping downwards below overlying sediments (Figure 32). The position is marked for a further 350m by a long sinuous shell mound – although the cliff is not visible at the surface, and was only located by auguring. This would have given the bay a stepped appearance, being shallower in the interior before dropping off into slightly deeper water in the mouth of the bay.

The interior of the bay is not marked by a cliff and the shoreline gradient would likely have been gentle. The distribution of sites in this area is irregular (Figure 32). Evidence suggests that shell sites are usually located at the closest convenient point to the shell beds. This is both from ethnographic evidence and from the location of shell sites across the islands. Therefore to create an irregular distribution, this area must have been sensitive to small changes in sea/land level, which would have resulted in a transitory environment where water levels changed from year to year. Sites accumulating at the water's edge one year might be submerged the next or stranded inland. As the deposits of some sites became deeper they would have become islands in years of high water level, resulting in them becoming self-selecting sites for occupation (Bailey 1994).

The eastern side of the bay is marked by linearly distributed shell mounds, interrupted in the centre for what is likely to have been a small

4. Site Distribution and Size – A Sign of Intensification?

inlet. The bay reaches a transition where it turns sharply inland and the cliff ends. At this point the distribution of shell sites changes from linear to irregular (Figure 32). It is probable that similar factors are at play in this area as with the western side, albeit on a more restricted level.

Many of the sites have suffered extensive damage from bulldozing to remove the material for the building industry (Figure 34). This has affected both sides of the bay; however the proportion of sites damaged drops to the west. On the eastern side most sites have been damaged or completely destroyed. It was therefore decided to concentrate research on the western side of the bay for this reason.



Figure 34: Site KM1057, an example of a badly damaged site (photo H Robson).

The survey found an interesting pattern in the surface composition of the sites; they were either composed entirely of *S. marisrubri* and *C. reflexa*, or entirely of *S. fasciatus*. A number of sites were composed of both, with a clear division through the mound separating the two. In this area the difference in colour between sites is a key indicator as to what the composition is. Darker (grey) coloured sites are predominantly composed

4. Site Distribution and Size – A Sign of Intensification?

of *S. marisrubri* and *C. reflexa*, whilst the lighter (cream/white) sites are *S. fasciatus* dominated.

Evidence for uplift in the inner bay comes in two main forms; firstly the basal heights for sites around the bay rises from an average of 4m ASL at the mouth of the palaeobay, rising to 6m on the western edge of the bay and 7m (with a maximum height of 11m) on the eastern edge of the palaeobay (Figure 32) - at the rear of the bay and into the channel linking the Khur Maadi bay to Janaba Bay West. When the DTM is viewed (Figure 32) it is clear that the palaeoshoreline does not follow the modern contour lines, as would be expected if the bay were in-filled. The height of the bedrock in the centre of the bay reaches a height of 7-8m ASL further inland, again demonstrating that uplift has taken place. The second piece of evidence comes from fault lines in the coral terrace which run east-west across the inner bay. These indicate that the ground surface has moved putting stress on the bedrock and faults fracturing it (Figure 35).

The outer palaeobay is marked by cliffs up to 1.5m high; these decrease in size towards the inner bay until they disappear under the in filled sediment of the bay. Behind the cliff line in the centre of the bay the sediment covering is thinner, and less extensive; this is visible on the false colour composite images. Further inland there is no sediment covering, and the bay area consists of uplifted coral terracing. In this area fault lines are visible on the satellite image, suggesting that tectonic uplift has occurred resulting in the faulting. Water transport is still active in the former bay, demonstrated by a wadi in the centre of the bay, which becomes an open channel near the shoreline. Long-shore drift is evidence on the satellite images (and in the sea), manifest as bars and spits which show the direction of the current from west to east. This would rapidly in-fill the channel unless there was at least occasional flow through the channel to periodically clear it. There are two possible causes of such a flow; either seasonal discharge after precipitation, or a spring which emerges in the bay.

4. Site Distribution and Size – A Sign of Intensification?

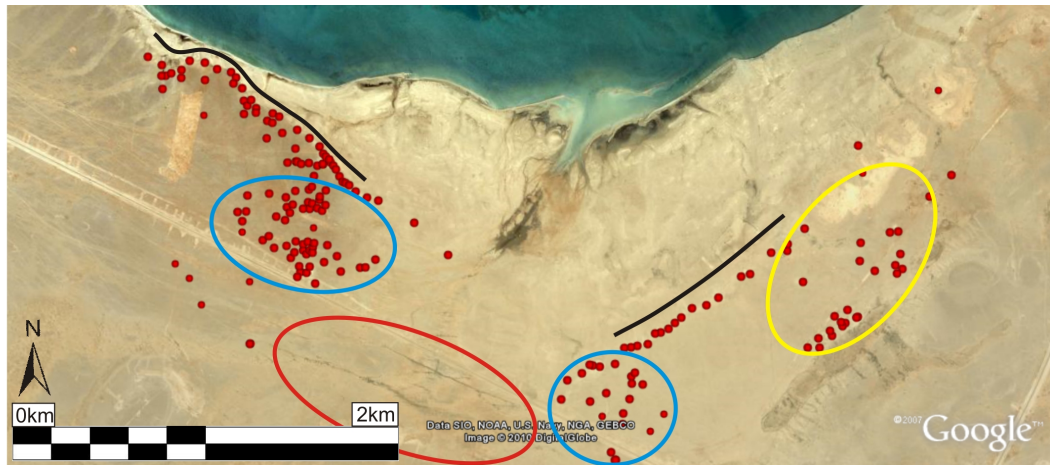


Figure 35: The extent and sites of the Khur Maadi bay. Features highlighted are: red dots are sites; blue circles highlight broad distributions; black line follows the cliff (note linear distribution of shell sites along the top of cliff); yellow circle indicates possible inlet along cliff.

4.3.4 Gandeel Peninsula – GP

The area designated Gandeel Peninsula covers a large area, incorporating the Harid Bay and Gandeel Peninsula further north. This area was visited in 2006, 2008 and 2009. No sites were found on the southern and eastern sides of the bay, however in the northern area there are extensive palaeoshorelines marked by low cliffs, which are topped by shell sites (Figure 36). This group of sites is composed of an unbroken line of shell sites that line the cliff. There are a couple of exceptions, where sites (or groups of sites) are located slightly inland from the main group. The palaeoshoreline has some small bays, and a number of islands, most of which have sites on them (Figure 37).

4. Site Distribution and Size – A Sign of Intensification?



Figure 36: Shell mounds on top of cliffs in the Gandeel Peninsula (photos H. Robson).

4. Site Distribution and Size – A Sign of Intensification?

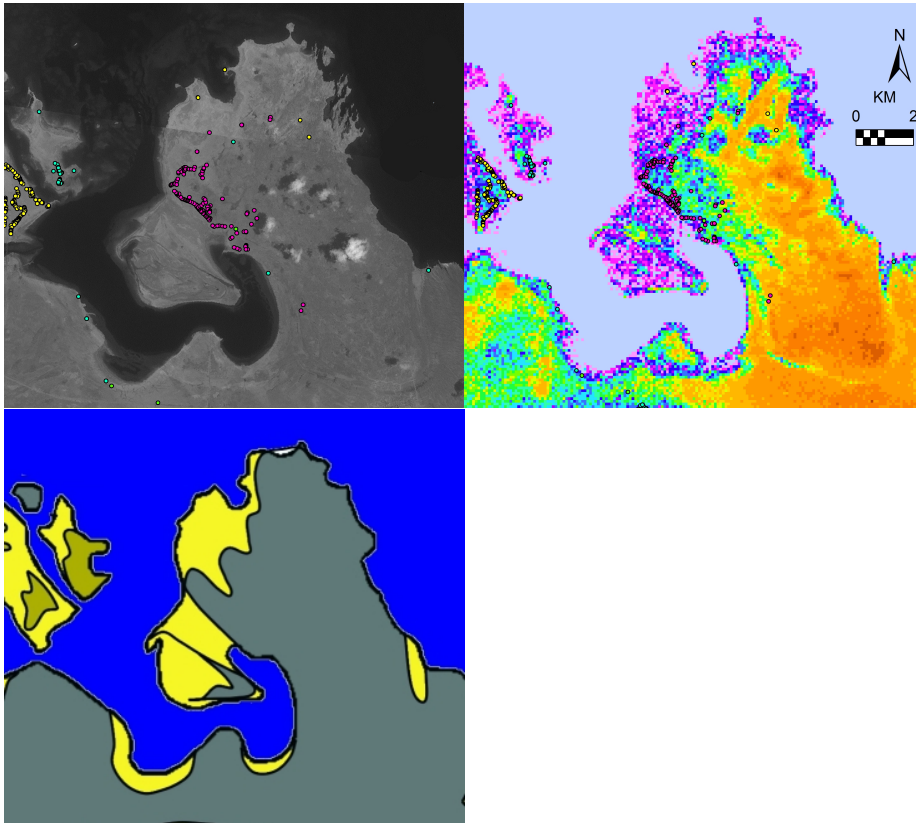


Figure 37: Gandeel Peninsula, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

As can be seen from the distribution of sites, most are concentrated in one area of the Gandeel Peninsula. There are several possible area specific reasons for this. The eastern shoreline of the Harid Bay is the location of the annual Harid festival – where the Harid fish congregate during Easter. The event is gaining popularity, with the Saudi Royal family now attendees of the festival. As a result development is taking place to commercialise the proceedings: car parks, viewing areas, access points to the beach and lighting have all been constructed along the eastern coastline in the last couple of years. Out in the bay are foundations for a removable mesh fence, which is put in place once the fish have entered the bay to prevent the fish leaving – so that they can all be caught. This development may have destroyed any evidence of sites along this section of coast – if there were any there to begin with.

Along the northern coastline it is very rough terrain, with high cliffs making access to the shore hard. In other research areas this has not restricted

4. Site Distribution and Size – A Sign of Intensification?

prehistoric shellfish exploitation, however there is the possibility that ecological conditions were not suitable for productive shell beds, except in occasional small bays.

The average basal height of sites along the northern peninsula is 5m, with a maximum site height of 8m and minimum of 2m. The cliff-line along this section of shore is prominent, and in places in excess of 3-4m high. Between these cliffs and the modern shoreline there are depositional sediments. It is unclear whether the retreat of the sea is due to tectonic uplift or sedimentation. However the presence of well developed wave cut notches at the base of the cliffs would suggest that uplift has occurred, bringing these features above sea level. It is likely that sedimentation was occurring during the deposition of the shell sites, and that these supported communities of *S. fasciatus*.

The area would have been dominated by a shallow intertidal to subtidal shelf with several small bays. The size of the shell mounds (some up to 3m high), suggest that the shell beds were productive or that the use of the sites was long lived.

The southern coast of the Harid Bay is characterised by two small bays that show evidence of sea retreat. The evidence for this comes primarily from the DTM (Figure 37). This is supported by field observations of deep deposits of marine sand, and false colour composite images that support this (Figure 37). The false colour composite images of the southern coastline of the Harid bay area do not show as clear an image as those for the Khur Maadi and Janaba West. Extensive deposits of sand across the area tell a story of inundation that is not immediately datable. Few sites were found in this area, but those identified can be used to identify the palaeoshoreline and follow them along the coast.

The sites discovered on the Gandeel Peninsula are predominantly located on a cliff-line, which can be tracked in the false colour composite image as the boundary between sand and fossil coral bedrock. The sand

4. Site Distribution and Size – A Sign of Intensification?

is the area that was once covered in shallow water. This line of sites is short; the density of sites reduces to the north where the terrain becomes rougher. Several small bays along the north coastline have isolated shell middens of indeterminate age.

4.3.5 Farasan East – FE

This research area covers the eastern side of Farasan Al-Kabir, encompassing the ferry port, and the entire eastern coast of the island, stretching along the southern coast meeting the Janaba East study area. The northern end is inaccessible and dominated by a high and steep cliff with little access to the shore. There is one large inlet in which the modern ferry harbour is located. From here the central and southern area has an extensive palaeoshoreline, up to two kilometres inland. This is variable, being marked in places by a cliff and in other areas by nothing more than shell sites on a gently sloping sandy incline. Some of the shell mounds in this area reach heights of 5-6m, whilst others are scatters (Figure 38). The area of exposed seabed is covered in a layer of sand of undetermined depth – as shown in the false colour composite satellite images that corresponds well with the DTM (Figure 39).

4. Site Distribution and Size – A Sign of Intensification?



Figure 38: A very large shell mound located on the end of what would have been a very low peninsula within the basin (photo G. Bailey).

Survey in this area found variable concentrations of shell sites. To the north few sites were found, owing both to the inaccessibility of the coastline to four wheel drive vehicles which hindered survey, and also to a continuous high cliff deterring coastal exploitation. However a few sites have been identified in isolated small bays. The central and southern areas have much greater concentrations of shell sites, which are predominantly linearly distributed along the palaeoshoreline. These palaeocoastlines are composed of a mixture of low cliffs and gently sloping sandy beaches.

This area has undergone extensive landscape change as demonstrated by the location of sites and palaeoshoreline. Interpretation of some parts of the palaeoshoreline is hard due to a combination of the absence of sites (whether actual or due to inconsistencies in the surveying), flat topography on the DTM, and palaeoshorelines which are not obvious on the satellite images. The height of the base of the sites varies along the coastline (from 4-12m ASL), primarily a product of the coastal topography (the presence or absence of palaeo-cliffs), but possibly also due to localised tectonics.

4. Site Distribution and Size – A Sign of Intensification?

There are several features of note in this area: at the northern end of the eastern coastline are a group of sites, which seem to represent a system of inlets and small bays. There are also two larger inlets on opposite sides of the island, which are linked inland by a depression, which runs across the island. The northern inlet is where the modern ferry port is located; the southern inlet is defined by a cliff-line and is no longer on the modern shoreline. A number of sites around the southern inlet suggest that it was active at the time of prehistoric shell midden accumulation, however no such sites have been found at the northern inlet. Whether this is due to modern development, incomplete survey of that area or is a true representation of the archaeology will require further research to resolve.

4. Site Distribution and Size – A Sign of Intensification?

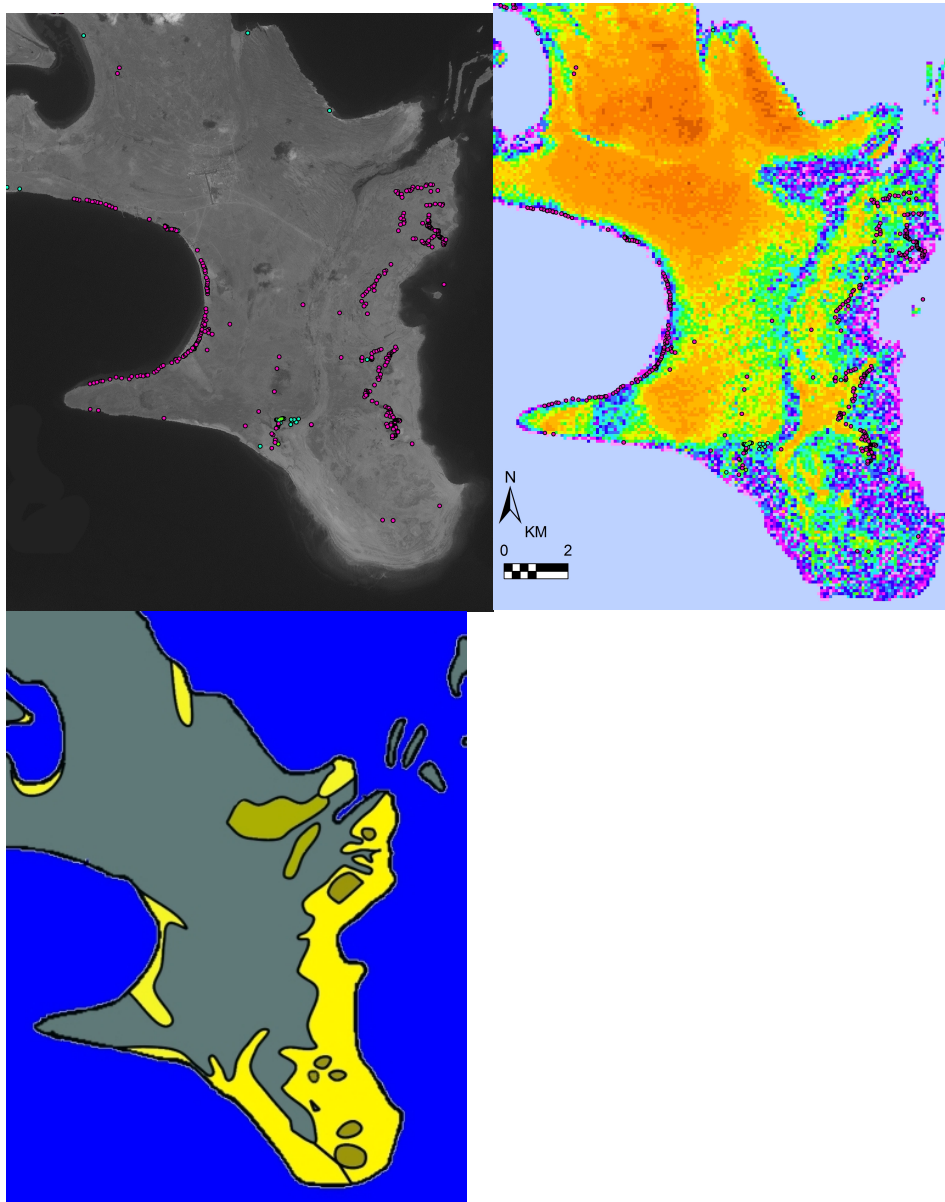


Figure 39: Farasan East, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

4.3.6 Northwest Farasan – NF

The north-western side of Farasan Al-Kabir is described as a single research area, Northwest Farasan, extending west from the Khur Maadi and Janaba Bay West as a long peninsula. The highest terrain of the archipelago is in this area, extending up to 70m in height (Figure 40). The southern side of the peninsula is dominated by high cliffs which drop into deeper water; this area is unsuitable for shellfish exploitation, since there are few accessible habitats. This is supported by an absence of shell middens along this section of coastline. A few exist to the southeast on

4. Site Distribution and Size – A Sign of Intensification?

this coastline in close proximity to Janaba Bay West, where a narrow, shallow subtidal shelf exists; there are also a number of sites to the northwest where a headland protrudes off the coastline.

The northwest end of the island and northeast coastline both have a wider shallow subtidal shelf providing good conditions for shellfish growth. The majority of the shell middens are located along palaeoshorelines, demonstrating that these coastlines have undergone change. This is visible on the false colour composite images, which show sedimentation has occurred roughly following the palaeoshorelines (Figure 40).

The field survey extended along the coastline from Khur Maadi nearly reaching the end of northwest side of the island, however it did not quite reach it and the sites north of this were located on satellite images. Only a small section of the coastline on the Janaba Bay West side was surveyed, with survey extending only 1km northwest of the Janaba Bay West research area, and the rest being focused on the headland to the north. The intervening section was investigated through satellite image interpretation.

4. Site Distribution and Size – A Sign of Intensification?

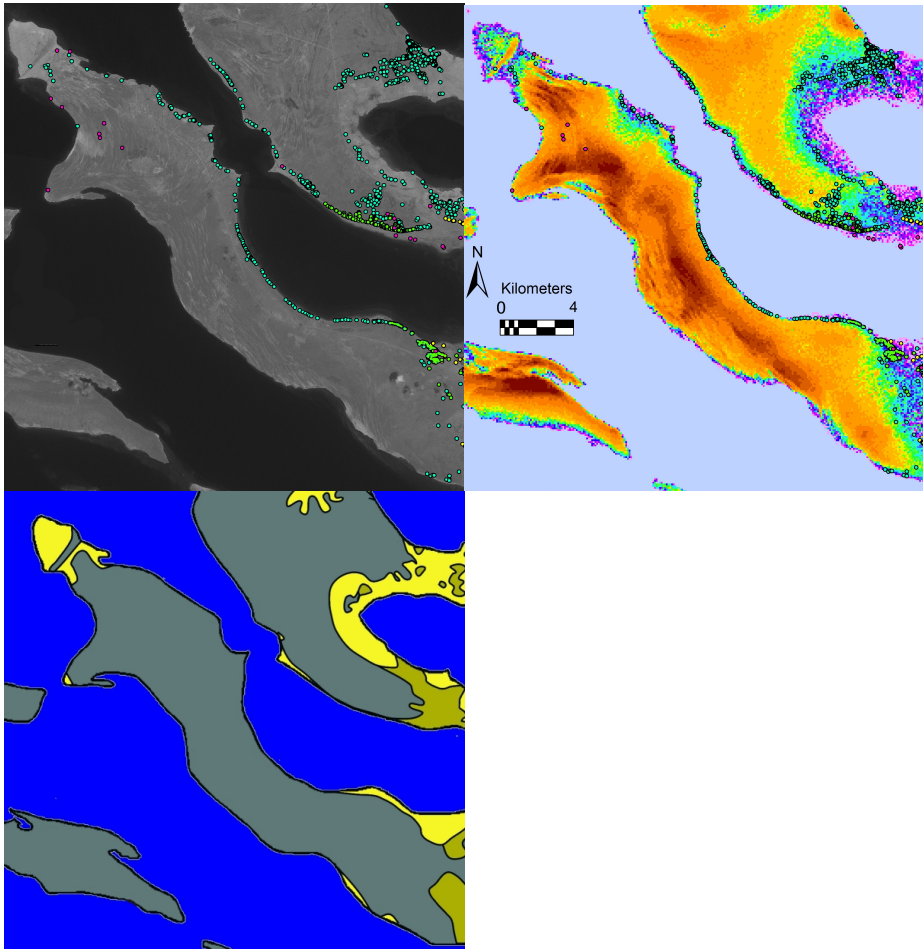


Figure 40: Northwest Farasan, from left to right, Satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

4.3.7 Southern Saqid – SS

The southern research area, visited in 2006, 2008 and 2009 has very variable conditions, with extensive sand covering on the southern peninsula, rising to bedrock in the north. The peninsula to the south has extensive palaeoshorelines which correspond very well with the DTM of the area (Figure 30). These palaeoshorelines meet the present day shoreline on the south west coast, which is marked by a cliff and shell sites, with some sandy expanses. These demarcate a series of small islands and inlets. The DTM shows extensive uplift, with many sites up to 20m ASL, whilst the FCC image shows extensive depositional sediments, which extend well beyond the palaeoshorelines marked out by shell midden sites.

4. Site Distribution and Size – A Sign of Intensification?

The sites in this area vary greatly in size. On the southern most palaeo-island the sites are predominantly shell scatters and low shell mounds, however at the tip of the palaeo-peninsula there are some extensive shell mounds (often composites of many sites) in excess of 5-6m. The composition of the southern-most group is predominantly *C. reflexa*, *S. marisrubri*, *S. fasciatus*, *C. ramosus* and *P. trapezium*, with *Arca sp.*, *Plicatula plicata*. and *Conus sp.* present, in some mounds abundantly.

The sites on the northern most of the two palaeo-islands have been largely destroyed or badly damaged. Every mound has had a bulldozer run through the middle of it destroying the stratigraphy. At the northern end of the palaeo-islands many sites have been completely removed along with the sand on which they were deposited. The local building industry has targeted this area because of the rich deposits of sand, which are 2-3 meters thick. The shell sites which are on top of these have been removed with the sand. Not much can be said about these sites, except that their composition is primarily *C. reflexa* and *S. marisrubri*, with *S. fasciatus* in some sites. The majority of sites are estimated to have been between 1-2 meters in height, probably closer to 1m. Some sites show evidence of perhaps being 2-3m, however this is based on the volume of disturbed material and it is unlikely that their true heights will ever be known. The average base area of sites is thought to have been around 10x30m.

The palaeo-peninsula which protruded from the south of the main island of Saqid is dominated by very high density of intact shell sites. These range from shell scatters up to large mounds 5-6m in height (Figure 43). These represent the largest sites encountered on the Farasan Archipelago. They were not single mounds, as is the case with the two largest mounds in the Khur Maadi group (KM1057 and its sister mound) and many of those the west shore of Janaba Bay West. Instead they were a composite of a group of sites – the largest and most prominent at the centre, with successively smaller mounds on the shoulders, moving outwards. These mounds clearly formed as an amalgamation of smaller

4. Site Distribution and Size – A Sign of Intensification?

sites, with multiple foci of activity. There are many examples of these, and this was clearly an important area for shell gathering activity. The surface composition of sites is a mixture of *S. fasciatus*, *C. reflexa*, and *S. marisrubri*.

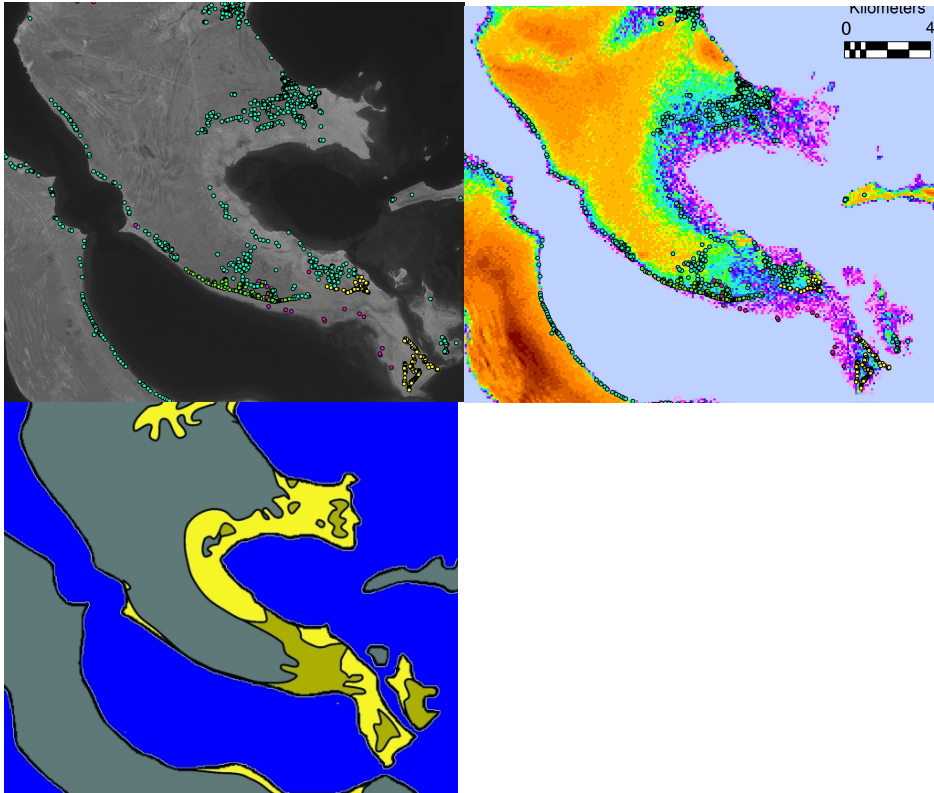


Figure 41: Southern Saqid, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

Concentrating on the southern peninsula it is clear that the coastline has retreated, and that the area was once extensively submerged (Figure 42). Two small islands stand out on the map both marked by a ring of shell sites (Figure 41). In the field these islands were hard to distinguish, owing to the flat but gently undulating topography. In addition the heat on the islands generates mirages which can obscure the lay of the land. However, when the GPS points are plotted on a map the two islands become more obvious. The southern peninsula of Saqid Island was much reduced, but still present. Both field observations and FCC images confirm that the southern peninsula has an extensive sand covering upon which the sites are located (Figure 41). These are depositional sands,

4. Site Distribution and Size – A Sign of Intensification?

indicating that the area was once submerged to a greater depth than when the shell sites formed.



Figure 42: View southwest showing extensive exposed shelf beyond palaeoshoreline (photo M. Williams).

The sites on the southwest coastline are still located at or close to the edge of the water, suggesting that the coastline in this area has remained stable since at least the formation of the shell sites. This is significant as it suggests that the retreat of the coastline on the southern peninsula is a result of tectonic activities rather than sea level change. Similar to Janaba Bay there are two coastal settings: cliffs and beaches.

4. Site Distribution and Size – A Sign of Intensification?



Figure 43: Large multi-centred shell mounds on the southern Sajid palaeo-peninsula. This mound exceeds 5m in height (Photo M. Williams).

4.3.8 Northern Saqid – NS

The northern area of Saqid is the least visited of all the areas of the central islands, with only brief visits in 2006 and 2008. The east of the islands has not been visited; data on this area comes from satellite image interpretation. These sites are numerous and closely follow the contours of the DTM and deposits of the FCC (Figure 44).

The east area has two extensive concentrations of shell mounds, neither of which have been visited in the field. The northeastern group consists of a series of linearly and irregularly distributed sub groups of shell sites, concentrated around what would have been a peninsula. This area is now incorporated into the mainland of Saqid Island. The southeast group are located along a long palaeoshoreline and is also composed of a mixture of linearly and irregularly distributed sites. These distributions are sufficient to be able to map the palaeoshorelines of this area.

4. Site Distribution and Size – A Sign of Intensification?

The distribution of sites across Saqid Island tells a story of change across the eastern side of the island, from north to south, and stability on the northwest. When the site locations are taken in conjunction with the island DTM and FCC images showing the sediment composition it is apparent that the coastline has retreated across much of the eastern part of the island, leaving exposed deposits of sand. The distribution of shell sites allows for a greater resolution of coastline reconstruction, and the conclusion that the southern peninsula of the island was once submerged, with all but two small islands under water. The stability of the western coastline, when taken in conjunction with evidence from other areas (such as Janaba Bay and Khur Maadi) suggests that the changes in the coastline are a result of local salt tectonics.

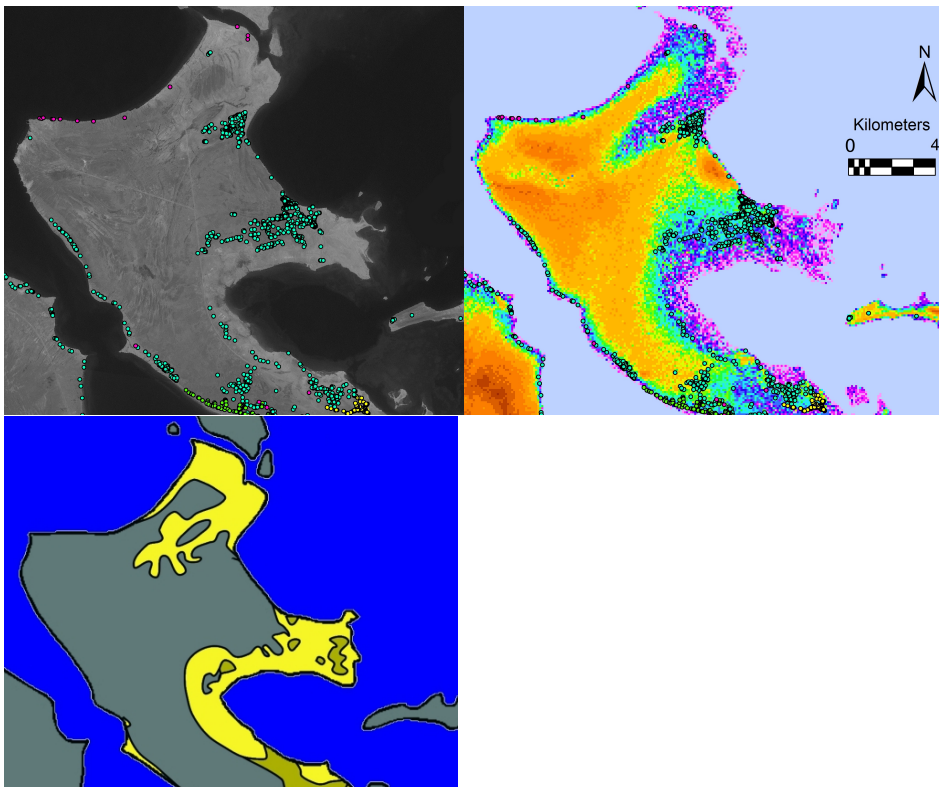


Figure 44: North Saqid, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

4.3.9 Qumah Island – QI

The north and west coastlines of Qumah are where the main concentrations of shell sites are located. This faces Janaba Bay and is

4. Site Distribution and Size – A Sign of Intensification?

just across the water from the main concentration of sites in Janaba Bay West. The northern distribution starts on the eastern end of the north coast, where the coastline is marked by a very shallow beach, which extends inland. It is marked by modern shell mounds and scatters along the present day coast, which are the product of recent fishing activities, which still continue (Figure 45). These are associated with fishing huts, which line the beach for 460m just above the high water line. A German coaling station is also located here, a relict of German colonial activity in East Africa. Inland behind these there are extensive shell scatters, which mark a palaeoshoreline. Dating this is uncertain; however the lack of pottery and its position suggest that it is likely to be prehistoric. The main settlement on the island is currently located some 700m inland of the fishing huts, and is surrounded by agricultural fields.



Figure 45: Modern fishermen's midden on Qummah (photo H. Robson).

To the west of the fishing huts on the modern shore there are extensive low shell mounds composed predominantly of *Chicoreus* sp.. These low mounds reach a maximum height of 1.5m; however the majority of sites are lower than 1m. The sites show clear structure, with depressions, small steep sided mounds c.1m high, and wide path/track ways which

4. Site Distribution and Size – A Sign of Intensification?

lead from the beach inland (Figure 46). These mounds appear to be related to more recent activity than the shell mounds on the palaeoshorelines behind them, possibly when *C. ramosus* was exploited for dye on a commercial scale. No finds were recovered to confirm this, but based on their location close to the modern shore and in front of the palaeoshoreline they are most likely historic.



Figure 46: More recent *C. ramosus* processing sites; in background inland older shell mounds are visible on palaeoshoreline marked by a cliff (photo H. Robson).

Dating of these deposits is uncertain, they may be associated with the German presence on the islands, but might also come from an earlier or later phase of activity. The pearl industry played an important role in the economy of the island, and this may have been connected with it. However, no material finds were recovered from the site during the survey, and so these sites must remain of uncertain date. Their position can be used to tell something about their associations; they align well with the palaeoshoreline on which the larger older shell mounds are located. However whilst the *C. ramosus* mounds are located on the sandy low-lying deposits, the larger older sites are located on a palaeo-cliff sitting over a meter higher. This is one indication that the lower lying sites

4. Site Distribution and Size – A Sign of Intensification?

must be younger, since they can only have formed after the sea withdrew. Had they been submerged they would have been reworked and other material incorporated. Their structure also hints at their recent nature, since the steep sided piles of shells have not had time to equilibrate to a lower angle. Neither has there been time for other material to become incorporated into the sites, such as windblown sand, and plant material.

Further to the west the palaeo-cliff approaches the sea, converging with the modern coastline (Figure 47). There is a continued presence of shell bearing sites along the top of the cliff, where the sites have a regular spacing. This configuration continues along the coastline as it turns south. There are a couple of short stretches of coastline where narrow sandy beaches have accumulated at the foot of the cliff. It is interesting to note that the FCC of the island suggests a greater extent of inundation than either the DTM, shell sites or palaeoshorelines suggest (Figure 48).



Figure 47: Palaeocoastline converging with modern shoreline in the distance (photo H. Robson).

4. Site Distribution and Size – A Sign of Intensification?

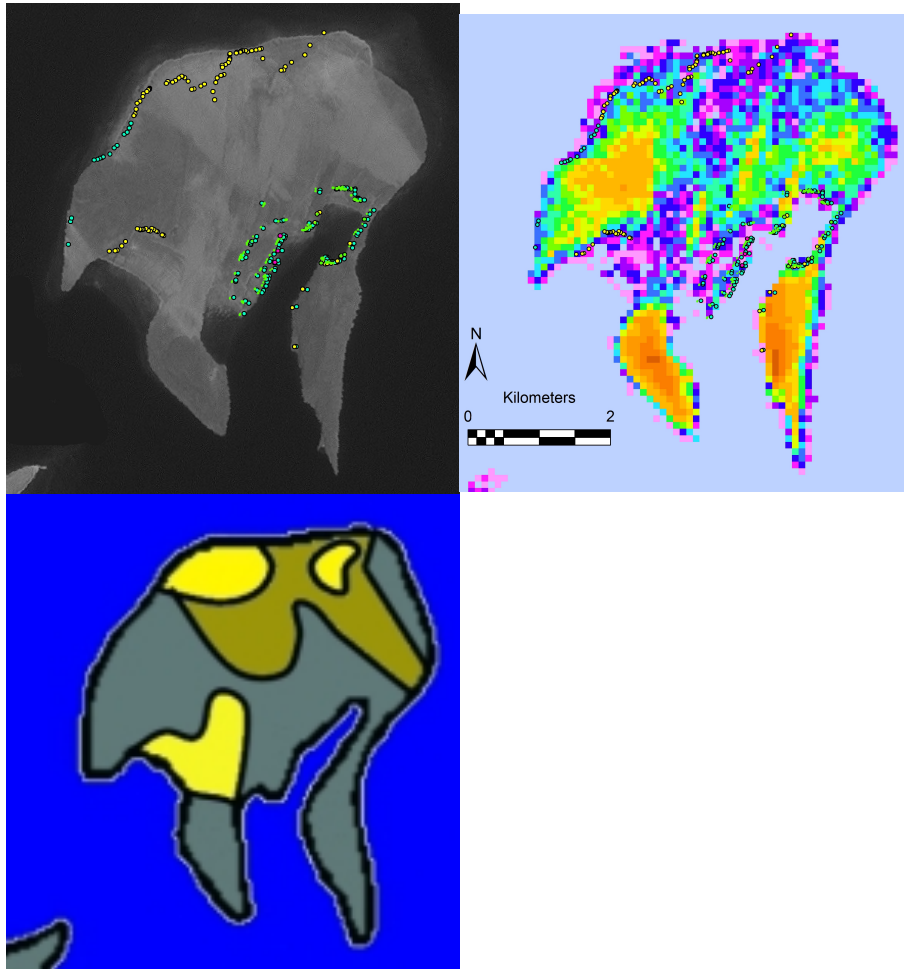


Figure 48: Qumah Island, from left to right, satellite image, DTM, FCC. Shell middens marked by dots with the same convention as for figure 26.

4.3.10 Qumah Bay – QB

The southern coastline of the island is dominated by Qumah Bay. It is made up of one wide bay, which extends 650m inland, and a second larger bay that reaches over 3.6km into the island. These bays are characterised by shallow sandy intertidal to subtidal shelves, which rise gently inland. The sides of the bays are dominated by cliffs some of which are over 20m. Shell sites are present along the majority of cliffs, and inland at the heads of bays (Figure 49). Both the location of sites and the topography suggest that the two bays were once joined as part of a more extensive network of channels when the sea level in the bay was higher than today.

4. Site Distribution and Size – A Sign of Intensification?



Figure 49: Upper photo shows high cliffs backing a palaeobay (photo H. Robson); lower photo shows large mound 2.5-3m in depth on cliff 3-7m high (photo G. Bailey).

The FCC image for this island shows extensive covering of sand stretching inland from the bay, and is mirrored by the DTM (Figure 48). This is also complemented by the satellite images; the shell site locations suggest even more extensive palaeoshorelines.

4. Site Distribution and Size – A Sign of Intensification?

There are some large sites in the bay; many perched on top of c.2-4m cliffs close to access points to the water. Many sites are now located inland, where the sea has retreated. The composition of many of the sites in the bay varies from those on the other islands. The key difference is the abundance of carpet shell, a bivalve that flourishes in shallow sandy subtidal and intertidal environments. This shellfish is either absent or present in very low concentrations in other research areas.

There are also small sites at the top of cliffs higher than 4m, at the top of access points. These access points are the only areas where it is possible to scale the cliffs; however they are precarious and would take some determination to tackle, especially when carrying a meal of shellfish. It is therefore no surprise that the majority of these sites are no more than scatters. Some are associated with pottery, suggesting a later date than the aceramic middens.

Almost every shoreline of the bay has shell sites present. However these are by no means the only archaeological deposits present here. On the top of one site (QB2085) there are three stone lined graves, of Christian or Islamic origin (owing to their orientation). In another area of the bay (next to site QB2085) there is the outline of an early Islamic mosque – marked out by lines of stones. This interpretation was carried out by one of our Saudi colleagues who is well versed in Islamic history. Other areas have stone structures inserted into the tops of shell sites; these are of indeterminate age, and no finds were associated with them.

One of the most interesting finds in the bay was an area with a high-density scatter of lithics derived from basalt. These were concentrated around sites QB2085 to QB2093. Finds were predominantly cores and debitage, however some scrapers and blades were also found. This area appears to have been an important area for lithic tool production, with material brought here for processing. Very few finds from this period, lithics or otherwise, have been found on the islands or at the excavations. It is useful to note that there are no sources of basalt on the islands.

4. Site Distribution and Size – A Sign of Intensification?

Indeed the only stone available is fossil coral or poor quality limestone. Any other stone material must have been imported from the mainland, from sources further up or down the coast where these can be found.

The shell sites in this part of the bay are more restricted in size, none being deeper than c.1m, with an average diameter of 25m across at the head of the beach. No excavations were carried out at this location due to its inaccessibility, however pieces of basalt were observed protruding from some of the shell mounds, but this could be the result of deflation or churning of the surface during subsequent site use. Much of the basalt was found on the coral terraces, making it impossible to stratigraphically correlate these to the mounds, or even other pieces of basalt.

The surface composition of sites within the bay differed slightly from those in other areas; *S. fasciatus* was a key component of most sites on Qumah, as would be expected with the wide shallow sandy bays. However in the bay sites there was a much higher component of carpet shell (*Arca avellana* – Figure 50) that inhabits coral habitats.



Figure 50: *Arca avellana*.

4.3.11 Size of Shell Sites

Of the 1038 sites surveyed, just under half (512) had their dimensions recorded. The full set of results only detail 476 sites (Table 4), this is due to damage inflicted on many of the surveyed sites by bulldozing activity.

4. Site Distribution and Size – A Sign of Intensification?

Of those still intact, there is a pattern of taller sites being wider; whilst shell scatters (<0.5m) occur at all widths.

	Width of Site																	
Height	1	2	3	4	5	10	15	20	25	30	35	40	45	50	60	70	100	Total
0.1	6	7	1	1	21	28	11	19		10		6	1	1	1	1	3	117
0.2							1			1				1				3
0.25					3	9	6	4		1		1			1			25
0.5					4	28	11	21	1	9		9		5				88
0.75						1		1			1							3
1					1	28	24	38		6	2	9		7	1		3	119
1.5						4	5	26	5	10		3		4	1			58
2							1	6	1	14		3		3				28
2.5									1	1		10			1			13
3										2		7	1	2	3	1		16
3.5												1	1	1				3
4																		0
4.5																		0
5															2	1		3
Total	6	7	1	1	29	98	59	115	8	54	3	49	3	24	10	3	6	476

Table 4: Table of measured survey shell site dimensions.

The results from the survey have been summarized in Table 5 below, giving the number of sites surveyed in each research area, and a break down of the average values for each research area.

Area	No. Surveyed Sites	Tot. Vol. (m ³)	Tot. Mass (kg)	Av. Vol. (m ³)	Av. Mass (kg)	Av. Height (m)	Av. Width (m)	Av. Breadth (m)
KM	82	19'151	19'150'572	234	233'544	1.1	18	17
SS	167	78'764	78'764'008	472	471'641	1.0	28	20
QI	55	18'717	18'716'971	340	340'309	0.8	31	20
QB	21	3'020	3'019'893	144	143'804	0.8	22	16
JW	151	19'923	19'923'322	132	131'943	0.8	17	16
Total	476	139'575	139'574'767	--	--	--	--	--
Average	--	27'915	27'914'953	264	264'248	0.9	23	18

Table 5: Summary of site survey measurements by research area.

The standard deviation of the average values in Table 5 are often larger than the average values themselves, making the average values somewhat redundant. This is due to the large number of shell scatters and low shell mounds at one end of the scale and a few very large shell mounds in each research area.

4. Site Distribution and Size – A Sign of Intensification?

What these figures serve to highlight is the vast quantity of shell which was processed at the sites. This is very suggestive of intensive activity however further research is needed to quantify its nature, in particular dating and an assessment of the formation processes and rates of formation of individual sites.

4.4 Reconstructing the Palaeoshorelines of the Farasan Islands

Analysis of site location combined with the DTM, FCC and survey data have also allowed for a reconstruction of the palaeoshoreline of the islands. These have undergone extensive change as shown in Figure 34 where difference between the modern and palaeo-shorelines is clear. These changes are most likely due to salt tectonics, which are still active today. The survey found evidence of this uplift, manifest in tilting palaeoshorelines, fractured rock and uplifted features.

There are extensive palaeoshoreline features on the islands, in several areas there are a series which are terraced. There are a number of methods used in this thesis to ensure that contemporary palaeoshorelines have been associated with each other in the reconstruction, and that palaeoshorelines from other periods have been excluded. The first sign is that the palaeocoastlines are at the same height above sea level (although uplift has not been linear in many places so this factor cannot be relied upon alone). The most useful indicator is the presence of shell mounds on them, as recorded in the survey and satellite image interpretation. However the shell middens do not necessarily originate from the same phase of accumulation, therefore it is vital to have secure dates for the sites in question. Preliminary work has been undertaken to address this and is presented in subsequent chapters. In some cases dating has not been possible for shell mounds located on palaeoshorelines; therefore an assessment of the nature and extent of the shell deposits has been considered in order to determine whether they are typologically similar to other dated sites. This includes

4. Site Distribution and Size – A Sign of Intensification?

the distribution and density of sites; their surface composition (if visited); and the extent of the palaeoshorelines compared to others of known date.

Inevitably the majority of sites could be broadly associated and therefore the palaeoshorelines on which they are located as well. The culmination of this is an assessment of the extent of the palaeoshorelines of the Farasan Islands and their reconstruction for the period of shell mound accumulation. This is shown in Figure 51 below. However it must be expressed that not all groups of shell mounds have been dated and these may prove to be earlier or later, thus changing the dates for the palaeoshorelines on which they sit. It is possible that rates of uplift were not continuous across the islands over time, resulting in different palaeocoastlines being active during different periods. Figure 51 may therefore be an oversimplification in the way that all palaeocoastlines with evidence of prehistoric shell mounds have been associated; only further dating programs will resolve this.

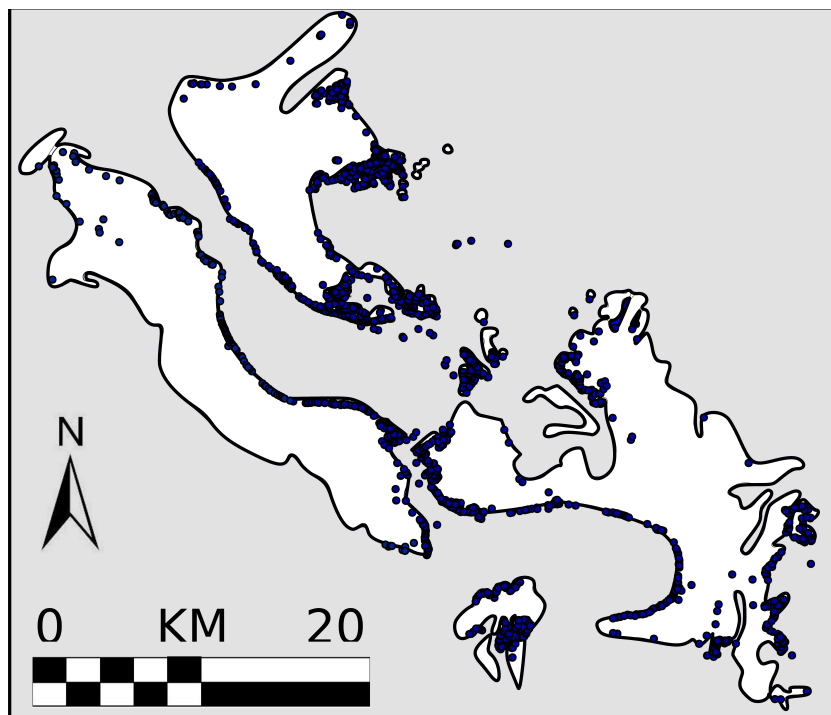


Figure 51: Reconstruction of the palaeoshorelines of the main islands of the Farasan Archipelago. Blue dots are sites, black lines are palaeoshorelines.

4. Site Distribution and Size – A Sign of Intensification?

4.5 Site location model

Over the course of the two field work seasons (2008 and 2009) the results from the satellite image interpretation were ground truthed. This allowed for the construction of a set of criteria for site location to be detailed, which resulted in the formulation of a site location model.

The distribution of sites broadly fits with Fischer's *Fishing site model* (1993). This ties in to the discovery of fish bones within many sites, suggesting that sites were located with the exploitation of a number of resources in mind, even if shellfish is the most evident. The targeted shellfish species also originate from a variety of habitats and depth, again suggesting that accessibility does not only apply to the immediate foreshore. Given that fish and shellfish share many habitats the overlap between the two models might not be surprising. However the key habitat seems to have been the shallow subtidal, with sandy substrates being only slightly more important than rocky. It is hard to assess the extent of prehistoric mangroves; no environmental work has been undertaken as part of this project. However the lack of the distinctive *Terebralia palustris* at the surveyed sites suggests that they played less of a role than on the mainland. In addition to species composition the morphology of shells of the same species can also inform on which environment was exploited, or be indicative of geomorphological change over time (eg Cabral and da Silva 2003).

A key output from this thesis is the production of a shell site prediction model for the region. This model uses a combination of DTM and or False Colour Composite satellite images to locate potential palaeoshorelines (see Romer *et al.* 2006). The key feature is a wide flat foreshore backed by a cliff, or higher ground (marking the palaeoshoreline). This can be highlighted by a change in geology, picked up using false colour composite images and on a DTM.

4. Site Distribution and Size – A Sign of Intensification?

High resolution satellite images complete the process by highlighting the unique spectral signature of shell midden sites. Using this data combined with site location from field survey it was possible to reconstruct the islands shorelines as they would have looked c.5500-5000BP.

Figure 52 is a modification of the Fishing Site Model, where shallow water has been shaded yellow and deeper water blue (left). Examples from the islands are shown to the right, where red dots mark sites, and black lines mark palaeoshorelines.

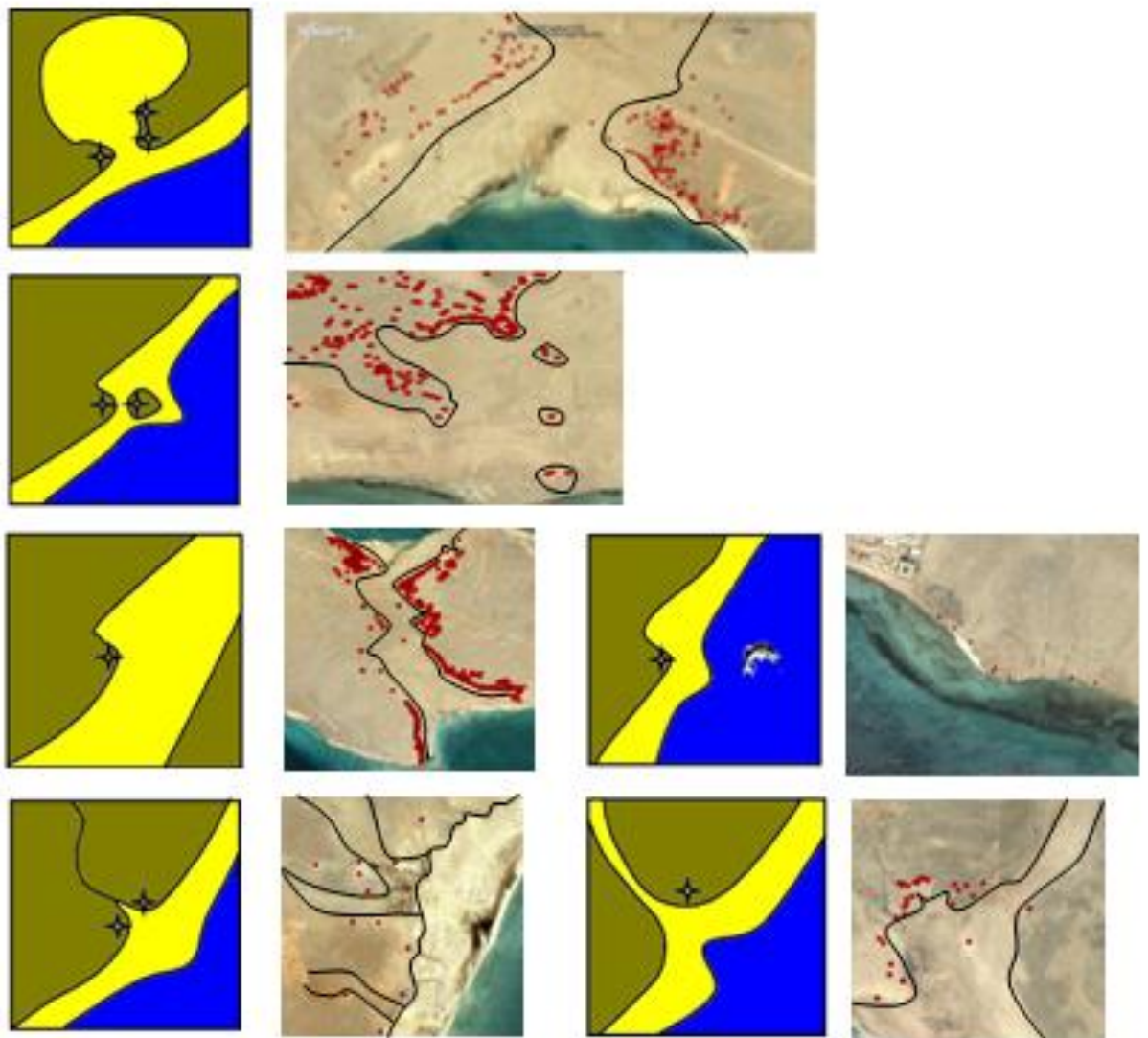


Figure 52: Fishing Site Model Modified for Shell midden sites on the left; blue is deeper water, yellow is shallow subtidal shelf, green is land and x marks site location (After Fischer 1993). Examples of the model are

4. Site Distribution and Size – A Sign of Intensification?

shown to the right, where red dots mark sites, and black lines mark palaeoshorelines.

The primary prerequisite for shell midden formation is a productive subtidal/intertidal shelf extending from the shore. Accessibility only becomes an issue where shell-beds are less productive. Initial indications suggest that the subtidal margin needs to be at least 100m wide, with a depth of 0.5-2m at maximum depth, but 0.5-1m is optimal.

The final scenarios of the original Fishing Site Model requires a river or estuary to be present, this configuration is active at the present day port on the islands, however it is unclear whether it has existed previously on the islands; a possible example has been included. Certainly few sites showed the presence of *Terebralia palustris*, a mangrove indicator. However on the mainland many of the shell middens are located close to wadis and are composed of the aforementioned species suggesting that this configuration has existed and been exploited there.

As well as being used to locate sites on the Farasan Islands this model has been successfully tested locating potential shell midden sites on the Dhalak Islands (Figure 53), the southern extension of the Farasan Archipelago in Yemen and on the mainland. The example shown below would make an excellent case study, since the isolation basin is likely to contain datable deposits documenting relative sea level change in the basin (eg Lambeck and Chappell 2001).

4. Site Distribution and Size – A Sign of Intensification?

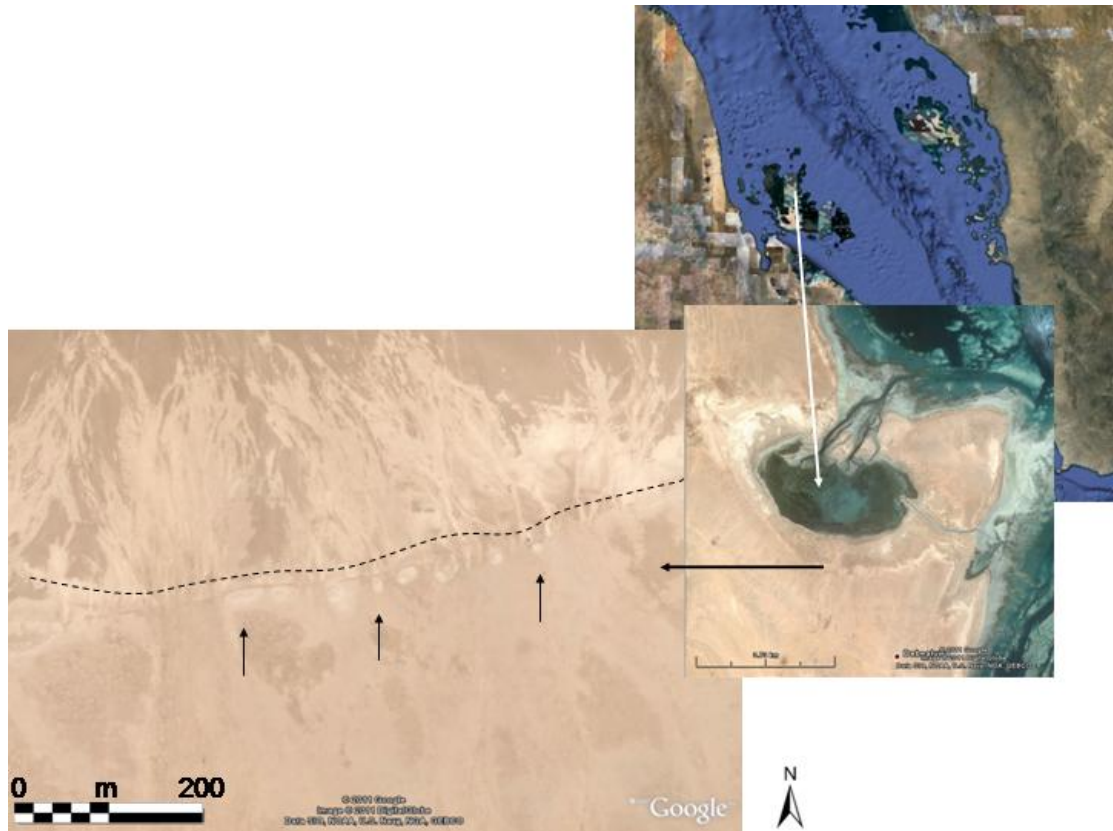


Figure 53: Sites located on the Dhalak Islands using site location model and satellite data. Dotted line marks probable palaeoshoreline; small arrows highlight probable shell midden sites.

4.6 Chapter Summary

This chapter has combined a number of different lines of evidence to map the prehistoric shell midden sites of the Farasan Islands. These sites are concentrated in high densities around the islands, often on palaeoshorelines. Associating these features and sites it has been possible to reconstruct the palaeoshorelines of the islands as they would have been during shell midden accumulation. These show that prehistoric shellfish exploitation on the islands was more likely to have been intensive than over a longer period. Similarities to mainland sites (both in terms of lithics and palaeoshorelines) suggest a time window between c.8000-4500BP. Exploitation on the islands was also strongly under the influence of dynamic coastal change as demonstrated by the extensive palaeoshorelines which add a further constraint to the timing if dated.

4. Site Distribution and Size – A Sign of Intensification?

As part of the process of locating sites a predictive model for site location was developed and tested. This has been applied to other areas in the region with the subsequent discovery of further sites.

These results have shown the need for further research. Excavation of selected sites would help to determine their rates and processes of formation which will inform on the intensity of exploitation. Investigating further sites through test pitting will help to resolve the age of the sites to determine whether or not they are the result of the same phase of shell mound building activity. Finally a dating program is needed to tie these themes together.

Chapter 5

Site Formation Processes and Underlying Social and Economic Processes

5.1 Introduction

This chapter will investigate the formation processes at work within a shell midden. Shell mound formation is an important line of research, having received little attention from the archaeological community. Gaining a better understanding of shell mound formation will help inform on coastal exploitation strategies, social and economic processes, and their response to change in the local environment. This will guide further lines of enquiry with the aim of determining linkages to local environmental change and social and economic activities. A key question is whether large shell mounds accumulated as the result of short bursts of intensive processing or longer episodes of lower level activity. The only way to answer this question is to excavate a site to determine the processes of formation and date these to assess the rates of deposition.

The potential of the Farasan Islands to record these lines of evidence has already been demonstrated in the previous chapter, with particular reference to the JW scatters located between the main palaeoshoreline and modern shoreline.

This chapter details the excavation of shell mounds. Each of these is the largest of its respective group, and this will help to answer the further question of why large shell mounds emerge to dominate a group of smaller sites. For each site the chapter will address the formation processes determined from the structure of the site, followed by an analysis of site composition and size to explore the underlying social and economic activities. These will inform on where further work is necessary.

5.2 Methods

The excavation of two large shell mounds constitutes a key component of this project. In order to fully understand the temporal and spatial evolution of a site it is desirable to excavate as much as possible, implementing a

robust dating program. The dating came second, and will be dealt with in a subsequent chapter. This chapter will deal with the excavation.

The objective of the excavations was to excavate a continuous section through the deposits on an axis which exposed the deepest deposits of the sites. This would reveal important information on the composition of the sites, and their internal stratigraphy, informing on the processes of formation.

Two key sites were selected for excavation in this study. Both have suffered damage, and both under threat of further destruction. The two sites chosen were JE0004 from Janaba Bay East, and KM1057 from the Khur Maadi. The first challenge was finding sites suitable for excavation: they would need to be accessible by 4x4 in order to facilitate transport of people, equipment and samples to and from the site. They would also need to be accessible from the town of Farasan where the team would be staying.

The excavation techniques varied between the two sites, being tailored to the local conditions. However the recording and post excavation methods were kept the same at both sites in order to maintain consistency of results. Single context recording was employed, with planning and section drawings completed where appropriate (eg Hawker 2001). Every context was also photographed in order to complete the descriptive record.

Before excavation began at JE0004 a grid was laid out in order to facilitate recording. This was not necessary at KM1057 since only a single section would be opened, and this was in an area which had been exposed by bulldozing. The JE0004 grid encompassed the site, with grids labelled alphabetically from west to east, and numerically from north to south.

Sampling strategies were consistent between both sites, with bulk and dating samples taken from appropriate contexts.

Dating samples consisted of either charcoal (where available) or siphon feeding bi-valve shellfish for radiocarbon dating, or *S. fasciatus fasciatus* shell for Amino-Acid Racemization (AAR) dating. Attempts were made to retrieve samples for Optically Stimulated Luminescence (OSL) dating; however the density of shells in the deposits hampered the successful retrieval of any such samples.

Bulk samples were taken from each context for analysis and where single context excavation was employed all of the excavated material from each context was processed (eg Orton 2000). Due to transportation limitations processing of samples was divided into two categories: scan or detailed processing.

The samples for scanning were to be processed during the fieldwork season on the islands. This processing involved a simple sieving technique using a large sieve operated by two people. The sieve had two mesh sizes to separate the material, the first of 2mm, and the second of 1mm. Using these mesh sizes it was possible to sort the material whilst retaining small finds visible to the naked eye, such as small fish bones. This mesh size was selected based on the conclusions of the literature, which suggested that these sizes were best for small finds recovery – such as fish bones (eg Shaffer 1992; O'Neill 1993; Mowat 1994; Shaffer and Sanchez 1994; Stahl 1996; James 1997; Cannon 1999; Claassen 2000; Glasgow 2000; Mason *et al.* 1998, 2000; Shaffer and Baker 1999; Peacock 2000; Shott *et al.* 2002; Vale and Gargett 2002; Quitmyer 2004; Smoke and Stahl 2004; Wake 2004; Zohar and Belmaker 2005; Jenkins 2006; Partlow 2006; Bell 2009; Giovas 2009).

The purpose of the sieving was to gain a better understanding of each context, and detailed notes were taken both during excavation and sieving. Not only could the composition of shellfish species be recorded,

but also the presence of small or irregular finds which may not have been immediately apparent during excavation or in section. These include obvious finds such as fish bones whose presence might otherwise be overlooked without sieving either due to their size or low concentrations; manuports which occur in low densities but which can be picked up in bulk samples; and shellfish where their concentrations or size may be too low to detect in a context during excavation or in section, but become apparent during sieving.

The second category of bulk samples were those for detailed analysis. These were set aside and transported back to the UK. Due to their size and weight only a limited number could be transported. Bulk samples chosen for transportation were selected either where a continuous series of successive bulk samples could be taken through the full depth of a deposit, or where there was a particularly interesting or unusual context which demanded further investigation, such as from the grave cut.

To characterise any context as a single event is an over generalisation, since it could represent an amalgamation of smaller closely spaced events (all depositing the same or similar material). The key question is how does the deposit relate to the periods before and after deposition of the material? Or how periods of inactivity be represented within the deposit? In essence the question is what is the lifespan of each context, and what does it represent? In the sites of El-Gouna, reviewed earlier in this thesis, a number of “sterile” sandy contexts were found within the excavated shell mound; these were interpreted as periods of site abandonment. These were large events, but were not investigated in more detail. Micromorphology might be one useful avenue of investigation and has been used to great effect in Terra del Fuego where up to 20 microstratigraphic events have been detected within a context (Briz *et al.* 2011). For the purposes of this study the resolution of such events has been considered, but is too fine to be included in this study due to resource constraints. It must therefore be conceded that not only the landscape and the sites, but also the contexts which make up the

sites are all palimpsests of archaeological events. Therefore each context will be treated as a single event (or at the very least an amalgamation of consecutive events depositing near identical material).

5.3 JE0004 Results

5.3.1 Excavation

JE0004 was first identified in 2006, when a series of step trenches were excavated down the southern (seaward) flank of the largest shell mound of the group in Janaba Bay East (Bailey *et al.* 2007a, 2007b). The site is located in the research area designated Janaba East (Figure 54).



Figure 54: The location of JE0004.

This site is located on small but prominent peninsula with good visibility across the bay (Figure 55). In this area the cliff is undercut by three to four meters, which has resulted in collapse in places and loss of material on one side of the shell mound. Between 2008 and 2009 further collapse was observed, with one and a half meters of land lost, resulting in further damage to shell mound JE0004 (visible in Figure 55). Additionally the site is located between a harbour and a power-station/desalination plant complex, all of which are expanding to accommodate growth of demand

on the islands. It is anticipated that this site will be impacted upon by the development.

This site was selected for study because of its vulnerability to destruction and because it is the largest shell mound of the group. As discussed earlier, the 2006 step trenches uncovered a stratigraphy of alternating layers of clean *S. fasciatus* and ash/crushed shell. This opened a window onto the formation processes of the site suggesting repeated episodes of use centred around a hearth. It was therefore decided to continue excavation at this site, and to broaden the study to encompass the surrounding shell mounds. This work was started in 2008 and continued into 2009. JE0004 is 20m in diameter, and 1.5m deep at the centre which is the deepest point. The mound is conical and almost completely symmetrical except where truncated by the sea. The surface of the mound is covered in a matrix of highly crushed shell, predominantly *S. fasciatus*, which is embedded in a matrix of fine silt sediment, hiding any hint of the stratigraphy below.



Figure 55: Shell mound JE0004, located on a small but prominent headland that offers excellent visibility across the bay (visible in background of upper photo). The cliff is undercut by three to four meters under the shell mound, resulting in collapse – highlighted by arrow in upper photo (photos M. Williams).

The objective of the excavation of JE0004 was to expose a continuous section to bedrock through the mound on a north/south (sea to land) axis. This would pass through the deepest part of the mound, revealing the composition and stratigraphy of the site.

The methodology chosen was to excavate a transverse trench through the middle of the site from the north (inland) side of the mound, to link up with the step trenches excavated in 2006. Before work began, a meter

square grid system was planned across the site; this was arranged on the same axis as the 2006 step trenches (Figure 56). The x-axis (NE-SW) was labelled 1, 2, 3, etc.; the y-axis (NW-SE) was labelled A, B, C, etc.; each square meter was further divided up into 50cm² quadrants, labelled A, B, C, D, beginning in the northwest corner and working left to right. Thus the first grid square would be A1-A. The next stage was the re-excavation of the step 2006 trenches to reveal the stratigraphy, and section drawings were updated as necessary.

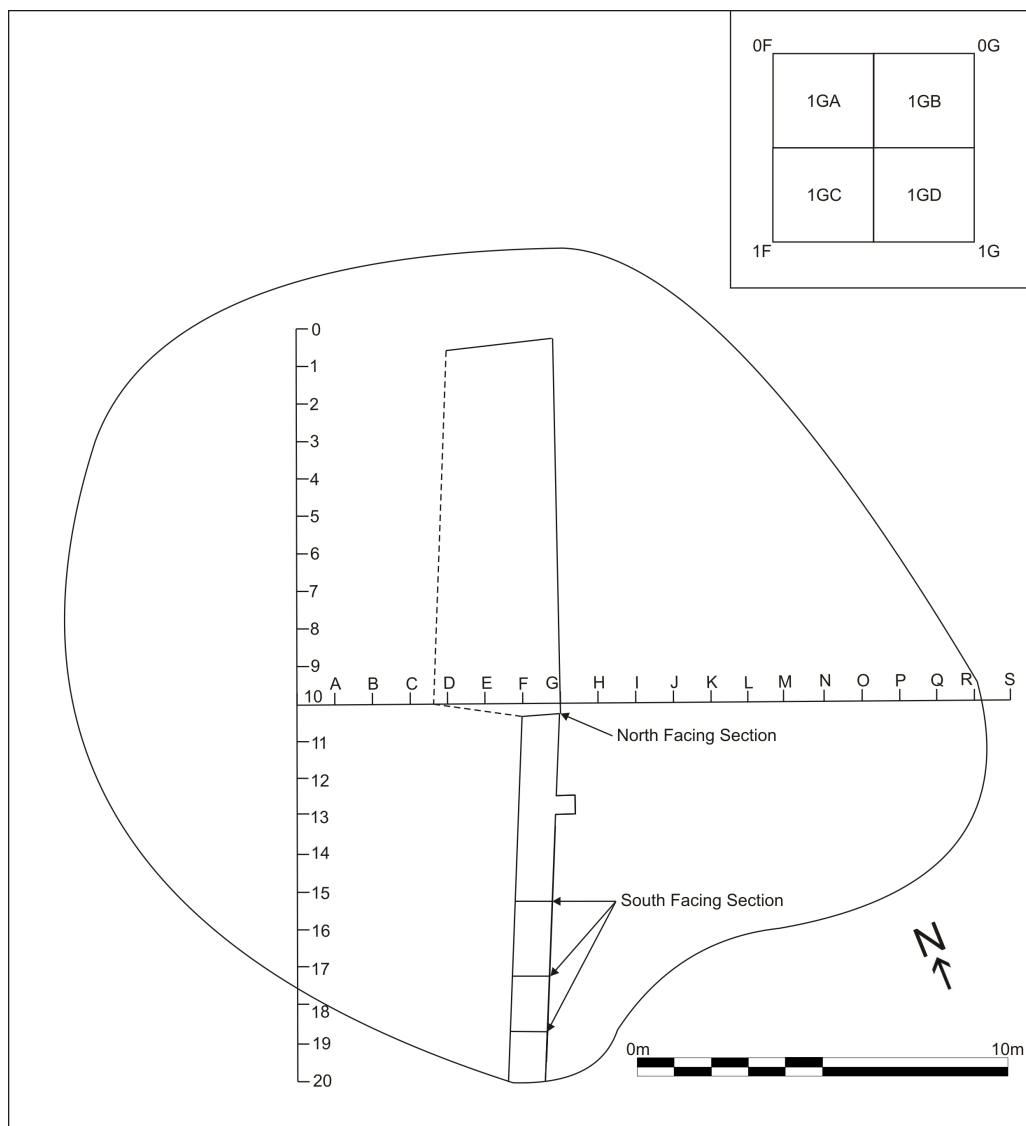


Figure 56: Plan of site showing grids and trenches excavated. Insert showing subdivision of excavation grids.

The transverse trench was started at the centre of the mound and aligned with the 2006 step trenches in order to provide a continuous section. The

material proved highly unstable and a mechanical excavator was used to open up the trench, working from the centre of the mound outwards (Figure 57). After a short period of excavation the machine had successfully exposed a trench approximately two meters wide and ten meters long, extending from the centre of the mound out to the northern (inland) edge. At this point the sections of the trench were highly unstable, and excavation was continued by hand. By this method it was possible to quickly expose a section to bedrock through the northern half of the mound. The material was highly unstable, and work slowed in order to minimise the risk of section collapse.



Figure 57: Mechanical excavation during initial stages (photo M. Williams).

The rationale behind using machine excavation is that shell mounds are composed of inherently unstable material. This is evidenced by the low angle of slope of their sides. Even to expose small sections requires the excavation of large trenches, since the material is liable to collapse and often needs to be stepped back to increase stability. To give an example of this in the most extreme cases, to expose a section through a 2m

deposit it is sometimes necessary to excavate a 3x3m² stepped trench with only a 1m² section exposed at the base. Cases such as this are rare, and although the material of JE0004 was unstable it was not necessary to open such a large excavation.

Machine excavation is by its nature a highly destructive procedure; however given the constraints of time and manpower this was deemed the most efficient way to excavate the mound. Excavating a site such as this by hand would take years of labour intensive work, and generate years more work in post-excavation analysis (Bailey *et al.* in press).

The final stage of excavation in 2008 involved linking the top step trench to the transverse trench through the middle of the mound, and excavating a small box trench in the centre of the mound. This work was completed by hand, using trowels, hand shovels, etc.; units were excavated according to stratigraphic layers using single context planning. Section drawings were completed to reveal a continuous section through the mound, although not to bedrock through the entire site (Figure 58). All material excavated by hand (which was not sampled) was processed either immediately onsite by sieving, or transported to a location nearby for processing by sieving and rough sorting.

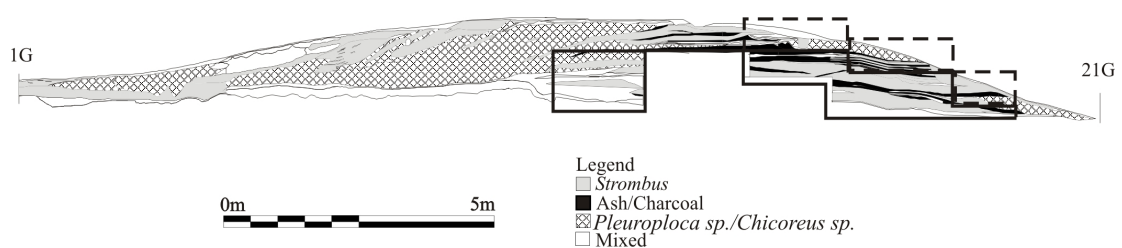


Figure 58: Simplified west facing section drawing of JE0004 combined 2006 (dotted boxes), 2008 and 2009 (solid boxes) sections.

Onsite sieving was accomplished using hand held sieves of 1 mm and 2 mm. In this way material could be scanned for finds, particularly small finds such as fish bones (Figure 59). Notes were compiled on the composition of the sediments and shellfish species present. The residues from the sieves were bagged, labelled and retained for later analysis.



Figure 59: On site sieving and sorting (photo H. Robson).

Material removed from the site was taken to the municipal compound. Here running water allowed wet sieving; however this was found to be an inefficient method of sorting the material. The extremely fine nature of the matrix between the shells resulted in the material forming a sticky paste which was hard to break down and clogged up the mesh of the sieve, taking excessive time. Dry sieving therefore proved to be the most efficient method of processing the shells. Having separated the fine material from the shell, the fine material was transferred to plastic sheets on which it could be sorted by hand.

On site sampling strategies included recovering any visible charcoal and recording the location on drawings. Bulk samples were taken from each excavated layer and in columns through the deposits directly from the sections, where each bulk related to one stratigraphic layer. Where deeper layers in excess of 10cm were encountered, arbitrary 10cm spits were used to divide up the layer in order to take bulk samples. Samples for AAR were also recovered, where possible from the same contexts as charcoal samples so that paired dating could be undertaken using radiocarbon dating on the charcoal.

In 2009 the step trenches were again reopened, along with the southerly most two meters of the 2008 transverse trench, sections 9G and 10G, exposing a north facing section into grid 11G (see Figure 56, 58, 60). The aim of the 2009 excavation was to deepen the step trenches from the south to bedrock, and work north exposing a section to the depth of the bedrock, whilst simultaneously excavating south into the exposed face of 11G to bedrock, and working towards the step trench. This would therefore expose a section to bedrock through the remaining half of the mound. Due to time and manpower limitations this was not realised, however the trench was extended to bedrock from 20G to 14G, and from 10G to 12G. In addition, the step trenches in grid squares 14G to 12G were lowered by 0.5-1m. This work was carried out by hand, with the help of members of staff from the Saudi Arabian Supreme Ministry for Tourism and Antiquities. All excavation was carried out by hand, using single context planning. Sampling strategies followed those of 2008.

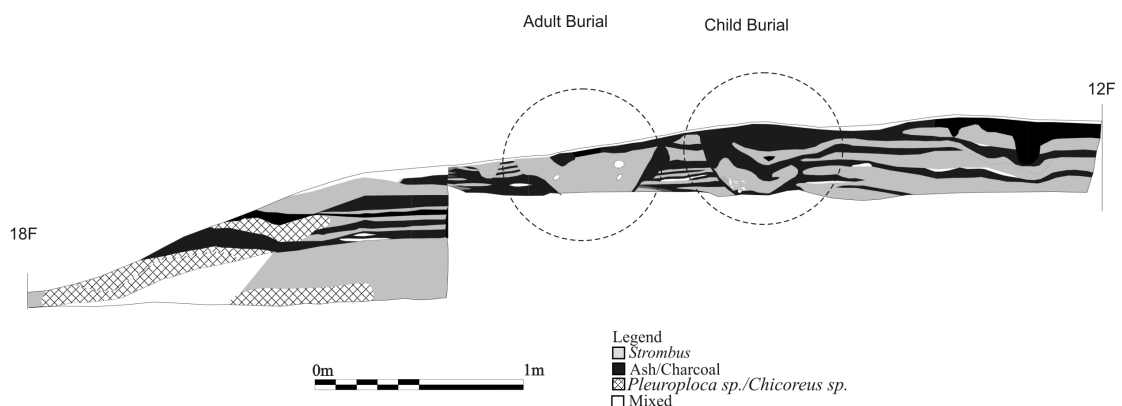


Figure 60: JE0004 east facing section between 12F and 18F showing grave cuts and cut features.

The two seasons of fieldwork exposed a continuous section through the shell mound. Although the excavation did not reach bedrock along the full length of the deposit, it has still been possible to reconstruct the evolution of the site and assess the formation processes. The earliest part of the mound has yet to be excavated.

The section drawing of the site displays two contrasting halves, showing two different modes and processes of accumulation. These areas clearly had different activities taking place, and it is obvious from looking at the

section that the northern (inland) half of the mound must be older than the southern (sea) side. The composition and stratigraphy of the site suggests that processing activities took place on the southern half, with the northern half being used as a dumping zone. The layers are highly stratified, with only one or two species being found within each context. It is also important to note that certain species are associated, being found in layers exclusively with each other, and very few other species. These are *C. reflexa* and *S. marisrubri*, and *C. ramosus* and *P. trapezium*. *S. fasciatus* and *P. nigra* are much more common in layers of single species. Species of shellfish found together are very similar both in terms of morphology and meat. *C. reflexa* and *S. marisrubri* are both bivalves which cement themselves onto coral at depth. *C. ramosus* and *Plaueruoploca* are both large gastropods which live on rocky substrates. These associations show that specific species or habitat were targeted and foraging expeditions were conducted with an aim.

First Phase

The oldest part of the mound is the southerly half closest to the sea. The layers of this part of the mound dip below those of the northerly half leading to this conclusion. This also fits in well with the distribution pattern of other smaller shell mound sites in the area, which are located within a couple of meters of the edge of the cliff. It appears that this mound started in the same manner as these other sites, but developed into a larger mound than those in the immediate vicinity with growth inland once the cliff was encountered.

This half of the mound would have been c.11m wide at its base before the northern half of the mound started to accumulate. At this point, before the northern half started to accumulate, it is estimated that the maximum height of the mound reached c.1.45m. The stratigraphy is composed of a number of alternating layers of clean *S. fasciatus* shell, layers of ash, and layers of charcoal and ash (Figure 61). These are the dominant constituents; however there are also layers of *C. ramosus*/*P. trapezium*;

C. reflexa/*S. marisrubri* and *P. nigra* which occur in varying sizes and densities. *P. nigra* forms continuous layers through this half of the mound between the ash/charcoal/*S. fasciatus* layers. The *C. ramosus*/*P. trapezium* and *C. reflexa*/*S. marisrubri* are more commonly distributed towards the periphery of the site.



Figure 61: Coastal west facing section from JE0004 grid squares 14G-16G showing distinctive charcoal and clean *S. fasciatus* layers (photo H. Robson).

Complexes of hearths can be seen in this area of the site, with a prominent distribution in grid squares 16G-17G. There are also several disturbances in this area of the mound. In section 15G was a small cut, which might be interpreted as a post-hole; the steep nature of the sides of the cut indicate that something was stopping the sides from slumping. There are other explanations for this such as digging, burrowing, etc. which were rapidly filled, and one small cut does not make a post hole. However two more similar features were found in the stratigraphy.

This section of the mound appears to have been subject to erosion by the sea. Between 2008 and 2009 a large section of cliff was observed to have fallen into the sea. The disturbances in 18G appear to be much

older, although it is clear that the section has been disturbed. It is likely that an earlier cliff fall had resulted in the destabilisation of the mound, and subsequent slumping of material in this area. Many contexts on this side of the mound stop at the surface of the mound, as if truncated, a probable result of erosion described above.

There are three disturbances in the southern section of the mound, which could be interpreted as postholes. One is located in grid square 15F-C to the south of the second burial, the remaining two are located in close proximity to each other in grid squares 12F-A and 12F-C. A final area of disturbance was found in grid square 11G.

There were numerous fish bones recovered from this side of the site; in some cases small dense pockets were present in association with hearth deposits, and/or *S. fasciatus*.

Second Phase

The northern side of the mound formed during a second phase of shell mound building activity with horizontal accumulation dominant. This side of the mound is dominated by thicker layers of the large gastropods *C. ramosus* and *Plueroploca* (Figure 62). These form very loose deposits, which are unconsolidated and have no matrix between the shells. There are discrete pockets of *S. fasciatus* within these layers, sometimes associated with fragments of charcoal. The bivalves *C. reflexa* and *S. marisrubri* are also present in many contexts, and there are occasional layers of *P. nigra*.

5. Site Formation Processes and Underlying Social and Economic Processes



Figure 62: Inland west facing section from JE0004 grid square 11G showing distinctive loose layers of larger shellfish species (photo H. Robson).

Some features which could be postholes were also found in this area (Figure 63). There are some features consistent with disturbance in grid squares 3G-C and 4G-A, which could potentially be interpreted as these.



Figure 63: Possible post hole in JE0004 gridsqaure 12F (photo H. Robson).

In grid square 8G a number of contexts appear to be truncated; as they near the surface of the mound they end abruptly, consistent with having been disturbed. Since this is on the land side of the mound this could suggest a number of scenarios. It is unlikely that any coastal erosion would have resulted in the truncation of these layers without major disturbance to the seaward side of the mound. Despite there being evidence on the coastal side for coastal erosion, it is inconsistent with a disturbance on this scale with no obvious signs of disturbance between 9G and 17G. It is therefore likely that this side of the mound has been altered by anthropogenic activity post deposition.

Truncation also occurs in square 14F-15F where the adult burial shows signs of erosion, but this does not appear to be linked with that of 8G. This will be covered in more detail below.

It is likely that these events are related to traffic over the mound after the site went out of use. The site is covered with a homogenous surface layer of highly crushed shell, most likely composed of elements of these lost layers. It is probable that this has been accelerated in modern times with the advent of 4 wheels drive cars, and the close proximity of the site to the power station, which has a road offering easy access to the top of the cliff.

Despite losing some parts of the stratigraphy it is still possible to reconstruct the formation processes of the site.

Later Burials

Two burials were found inserted into the southern side of the mound, although their stratigraphic relationship is unclear, and they are most likely later insertions. Section collapse on the east facing section of the top step in the centre of the mound revealed the presence of the two burials. The cuts of these features would have been inches from the sections which had been cleaned back in 2008. The section collapse was

very fortuitous, as it revealed an aspect of the mound that would have otherwise remained hidden during the excavation.

The first burial was located in grid squares 15F-A to 14F-C, and was delimited by a well-defined cut at the southern extent of the feature in square 15F-A (Figure 60 and 64). The cut is less well defined to the north in 14F-C, although there is much evidence of disturbance in the sediments. The southern area of the cut is lined with charcoal, on which a lithic and some unusual shells had been placed (Figure 65 and 66). The lithic is a hammer stone made of basalt; above the lithic fragments of skull were found, with further bone fragments found immediately north. The bones were small and fragile, and had not preserved well. Analysis of the bones by Dr Hannah Koon suggests that they belonged to an infant between 3-6 years old (Koon pers. comm. 2010).

The lithic suggests that the grave originates from broadly the same period in which the mound formed, during the aceramic Neolithic; however it is still possible that the grave is a later insertion after the mound had gone out of use.



Figure 64: Child burial grave cut – skull fragments visible on left hand side of the cut with lithic below (Photo H. Robson).



Figure 65: Unusual shells (for site JE0004) found in association with the child burial (photo N. Al Shaikh).



Figure 66: Lithic found beneath child skull (Photo N. Al Shaikh).

It would appear that the grave was cut and the excavated material deposited to the north in grid square 14F-C/14F-A before being backfilled. There are three possibilities as to how the charcoal and ash arrived in or near the grave cut at the time of burial: either burning was initiated in the cut, or charcoal and ash from a previous fire were introduced into the cut.

This could represent grave offerings, or perhaps cleansing of the grave prior to the interment of the remains; lastly it could simply be the result of the process of backfilling, where excavated material from the cut was reintroduced into the grave.

Following the deposition of the charcoal and ash the stone tool was placed onto the layer of charcoal, followed by the body. The body was positioned so that the head was on top of the stone tool. Following this the material excavated from the cut was pushed into the grave sealing it. This resulted in the turbulent nature of the deposits in the northern area of the cut. It is uncertain whether the ash and charcoal deposits are one singular deposit or two. Certainly in the vicinity of the lithic and skull the deposits appear to be separate, however this could be a product of the area being cleared of ash prior to the deposition.

Because of the poor condition of the bones it was not possible to determine whether the body was articulated when it was buried.

The second burial is located in grid squares 16F-A and 15F-C. This grave cut is larger and well defined. The northern edge of the cut is lined by ash and *S. fasciatus* in an ash matrix. This could be evidence for a similar preparation of the grave cut. However the presence of *S. fasciatus* in the ash, the lack of clearly defined charcoal, and the abundant presence of ash and *S. fasciatus* in the contexts through which the grave cut was excavated complicate the interpretation. It is a distinct possibility that the presence of ash lining the grave cut is a result of the initial excavations of the grave prior to the burial.

The remains in the grave cut were in a poor state of preservation, although from the size of the bones it was possible to immediately identify the bones as adult. Many of the bones were so degraded as to be nothing more than dusty stains within the grave sediment (Figure 67). However it was possible to determine that the skeleton was likely articulated when buried, and was buried in an upright crouching position, leaning back

slightly, and facing out to sea. This was determined from the position of the legs, arms and hands. Unfortunately the shoulders, upper vertebrae and skull were absent, probably due to poor preservation. From the position of the burial it seems likely that the absence of these bones is due to erosion of the surface of the mound and poor preservation, most likely as a result of coastal erosion. A conservator was called from the Riyadh, and was able to salvage some of the long bones; however the fingers, toes, vertebrae, pelvis and shoulders were irrecoverable.

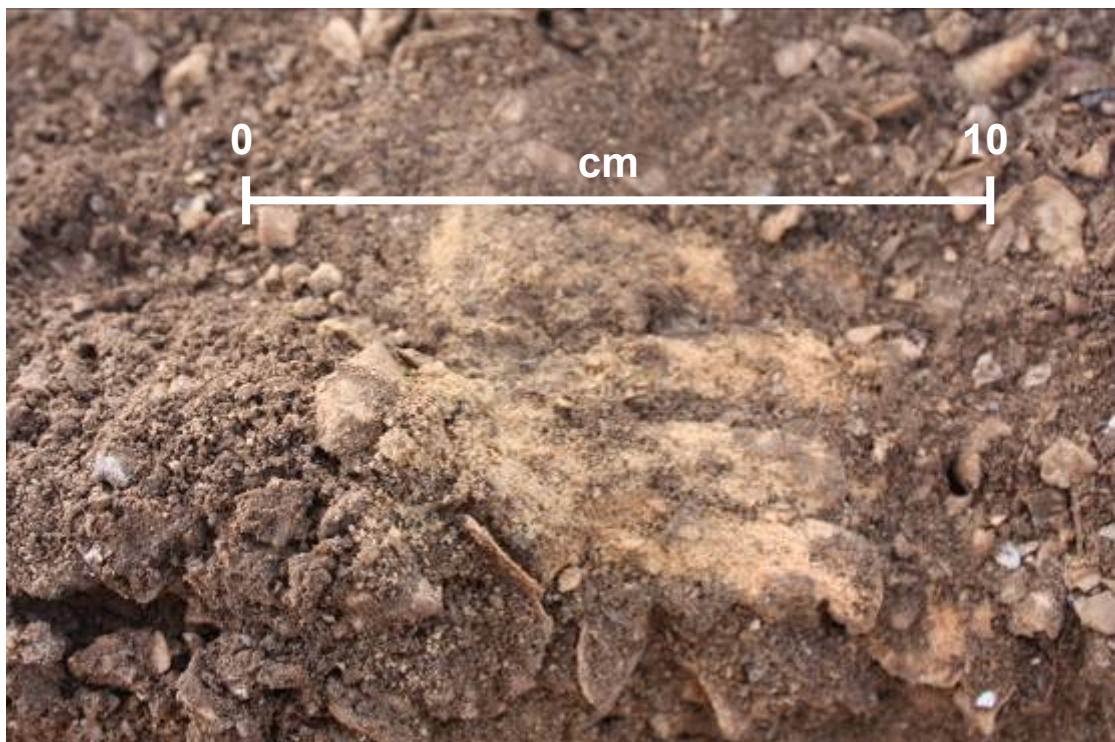


Figure 67: Dusty stains of finger bones (Photo H. Robson).

5.3.2 Reconstructing the formation processes of JE0004

Using the section drawings and context notes recorded during the excavation it has been possible to reconstruct the general pattern of mound formation, and determine that it happened in two phases. This is done primarily by construction of a Harris Matrix (eg Lucas 2001), whereby each individual context is assigned one of four relationships to its surrounding contexts, which it comes into contact with. These are **Earlier** (lies beneath or is cut by overlying context); **Later** (lies above or cuts through underlying context); **Contemporary** (were deposited at the

same time); **No relationship** (it is impossible to determine the relationship between the two contexts). Using this methodology it was possible to determine evolution of the excavated area of the mound. Although this model is limited to the results from the excavation, it shows a strong pattern, which likely continues throughout the rest of the site; unfortunately this can only be tested by further excavation. The key limitations are that the model only comes from a single transverse trench across the site, and that this trench does not reach bedrock along its entire length.

However the results strongly suggest that the site developed in two distinct phases. The first phase of growth appears to have been initiated from a single point of origin. However without information on the basal deposits of 12G-15G it is impossible to determine where this point of origin might be, and it is possible that it could be anywhere between 12G and 18G. Due to this gap in the data there are several possible different interpretations of the initial growth of the mound, with growth models constructed for the site (Figure 68).

5. Site Formation Processes and Underlying Social and Economic Processes

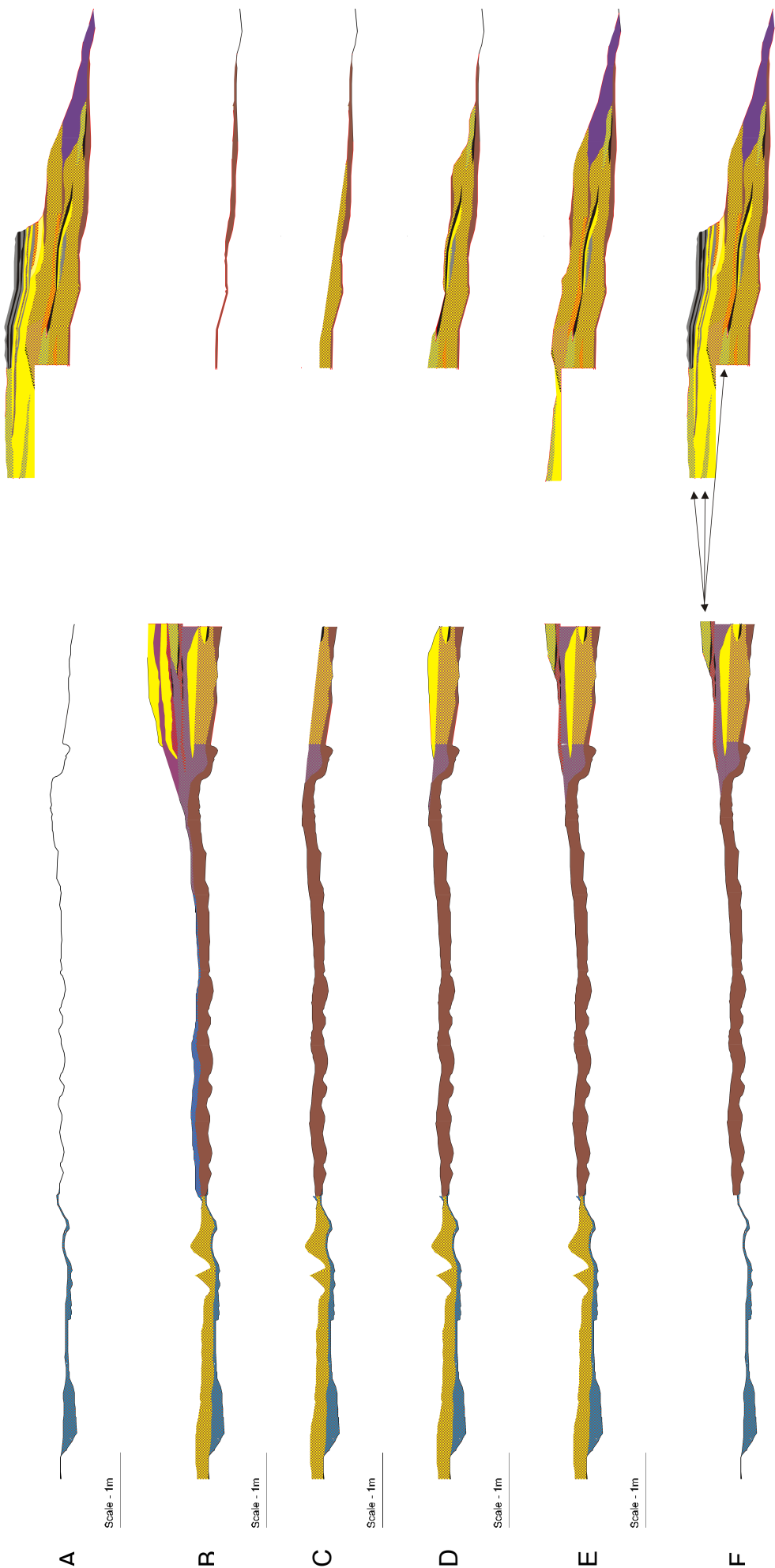




Figure 68: Reconstructing the growth of JE0004. A and B are extreme scenarios where site initiation is either north or south of unexcavated section. C – E hypothesised growth of mound linking unrelated contexts from the south and north of the site. F – Showing the complexities of correlating similar layers across the unexcavated section. G – J reconstruction of the mound based on the superposition of layers, clearing showing the two phases of mound growth. Yellow is *S. fasciatus*, grey is ash, black is hearth/charcoal, blue is *C. reflexa*/*S. marisrubri*, purple is *Pinctada nigra*, red is *C. ramosus*/*P. trapezium*, brown are brown organic sediments

The models C to F (Figure 68) are favoured in this case because they follow a more incremental even growth through the mound, as seen at other sites (eg the Sewee Shell Ring, Russo and Heide 2003). However none can be discounted until further excavation takes place exposing the central section of the mound to bedrock. If this is not possible a high resolution dating program would be the only way to determine the process of formation of this side of the site.

There is the possibility that this site could have originated from two sources; the area of the mound not excavated to bedrock could contain evidence for this. Indeed the section drawing shows an anomaly in 15G which could be interpreted as evidence for a multi-point origin. This feature is enlarged in Figure 69, and several possible interpretations for the feature are shown. The section (Figure 69a) shows layers which appear to be cross bedded; Figure 69b is a simplified sketch of this anomaly, showing how the layers abut. There are several possible explanations for this feature; the first (Figure 69c) is that the mound originated from two separate sites in close proximity (highlighted in yellow). As these grew they merged, forming the feature seen here. The evidence for this hypothesis is not strong, since the underlying strata in sections 15G to 19G do not support a point of origin in this part of the mound. However there may well be evidence for this in the unexcavated part of the site.

There are two further explanations for the cross bedding feature; the first is that it is a product of reworking of the material (Figure 69d). It is possible that an erosion event occurred creating a depression or pit within the strata coloured red; this feature was subsequently in-filled with a later deposit (coloured green).

The final hypothesis is that the feature is a depositional feature, caused by local variations in the way in which layers accumulated. Figure 69e shows how a small and localised episode of deposition has resulted in a small conical deposit (coloured red). Rapid deposition around this feature

would stabilise it, supporting the sides before it had time to slump, or be reworked by trampling.

The final conclusion on this feature will have to wait until further excavation reveals the extent of the anomaly in the section. However, based on the available data the most likely scenario is that it is a result of either a localised depositional process or an episode of erosion, or a combination of the two.

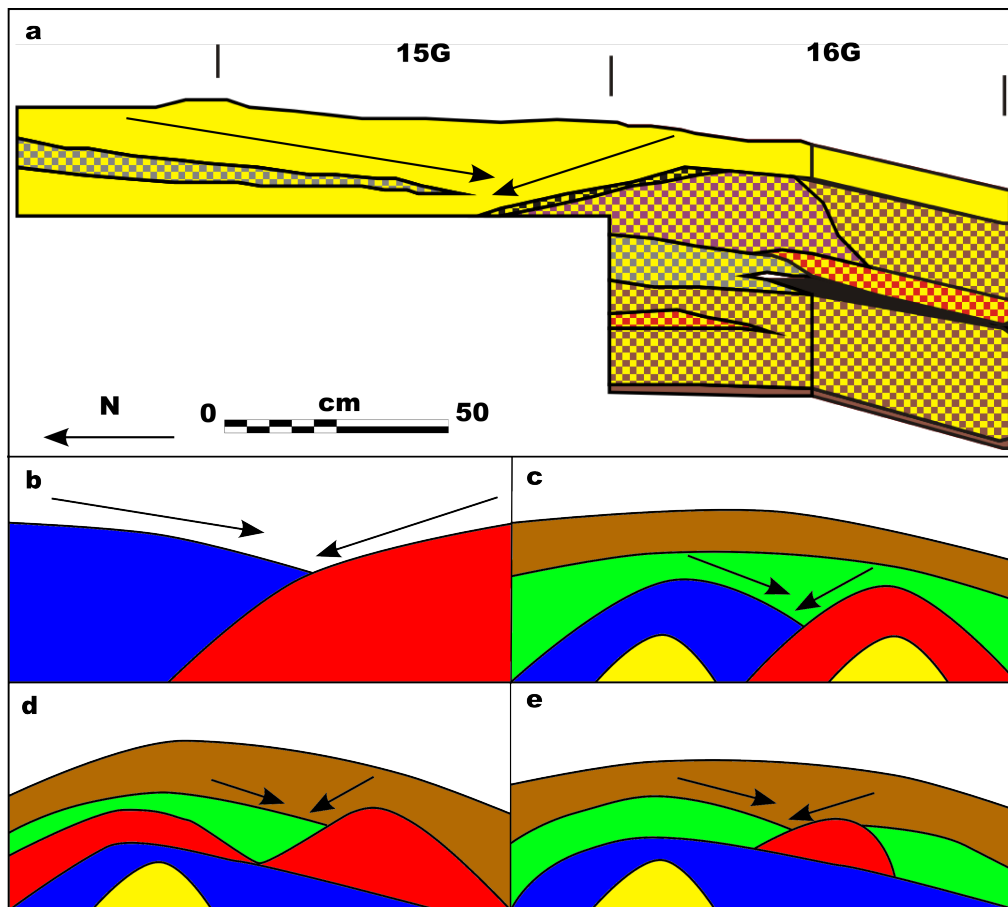


Figure 39: Depositional anomaly in section 15/16G of JE0004. a – the section drawing (arrows highlight cross bedding feature); b – simplified sketch of cross bedding feature; c – cross bedding interpreted as growth from two points of origin; d – interpretation showing cross bedding as an erosion feature; e – showing cross bedding as a depositional anomaly.

The reconstruction of mound growth is problematic due to the unexcavated area in the centre of the site. This area is key to understanding the early stages of site development, with many of the lowest layers of the mound emerging from this unexcavated area in the

section. Figure 68 shows a reconstruction of the development of the shell mound JE0004. A and B are extreme demonstrations of how influential the unexcavated part of the site could be to our understanding of the initial stages of development of the site. The three sites of JE0001, JE0002 and JE0003 are all small conical mounds which are focused and localised, and it may be the case that JE0004 started off in this manner rather than a broader deposit which build up into a mound. The first two reconstructions are unlikely to have happened, but they serve to highlight the possibility.

Figure 68 C to E are a hypothesised reconstruction of the early stages of the site, based on an initially broad deposition from which a mound developed, from shell scatter to shell mound.

The reconstruction “F” is to demonstrate the difficulties encountered in determining associations between similar layers on either side of the unexcavated section. On the northern side there is one context which is composed of *S. fasciatus* and ash; on the southern side there are three such layers, all of which are similar. These are highlighted by the arrows. Without further excavation it is impossible to speculate which southern layer corresponds to the single northern layer, if any of them do at all (as shown in A and B).

The final stages of site development are shown in G to J. G to H show a change in focus of deposition, in G mound growth is concentrated on the top and upper side of the mound. However in H the emphasis changes to the northern side of the mound, with substantial accumulation in this area in I and J.

The above shows that the mound conforms extremely well with the model proposed by Russo and Heide (2003), whereby accumulation is initially vertical followed by subsequent horizontal deposition. (This does not negate the possibility of some horizontal deposition, for example during the initial shell scatter in the sequence, however the over-riding direction

of accumulation is vertical). The initial phase is associated with activity centred on a complex of hearths, with *S. fasciatus* processing most visible. This was by no means the only activity during this phase, with a number of other species also processed including shellfish, fish and mammals. Layers of larger shelled shellfish accumulate towards the periphery during this stage, suggesting conformity to the toss/drop model. However the distinct species separation between most layers could be the result of targeted exploitation and processing activity.

The final stage of accumulation is clearly horizontal with very little vertical component. The section shows a focus of deposition to the rear of the mound; however it is likely that this occurred on all sides, only being visible in the exposed section. This is primarily associated with larger shellfish species; however *S. fasciatus* still plays a role, either in smaller capping layers, or discrete lenses often associated with charcoal. The primary activities in this part of the site appear to be the intensive processing of shellfish, with very little evidence for hearths found.

This reconstruction of the growth of the mound through the section drawings has allowed the processes of formation to be assessed. It also provides evidence for some of the underlying socio-economic activities behind these processes. Furthermore the marked change in formation processes could be a socio-economic response to environmental change. In order to explore these relationships further, it is necessary to look more closely at the composition of the site. The next section will therefore explore the composition of the bulk samples taken from the site.

5.3.3 Social And Economic Processes Behind Site Formation At JE0004

a) Site Composition

Information on the social and economic activities at a site can be accessed by looking at the composition of sediments. Bulk samples were

returned to York for more detailed analysis. It was hoped that these would also help to uncover any responses to environmental change at the site.

Ongoing work undertaken by Eva Laurie and the author is attempting to determine the composition of these samples. This involves sorting through the bulk samples taken from the site, first sieving them through a stack of 10mm, 5mm, 2mm, 1mm followed by 0.5mm mesh sieves. This serves to separate out the different fractions and facilitates analysing the material. The resulting sieve residues are commonly complete shells at the first (10mm) sieve, followed by crushed shell fragments, and finally different grades of finely crushed shell, sand, silt and ash. This material was analysed (each fraction in turn); first the shells were sorted according to species. Complete shells and fragments which had intact diagnostic features present (eg bivalve hinge; gastropod apex /outer lip) were measured, counted and recorded. Recording was completed according to a system devised by Laurie, which ensured all information was entered in a systematic and consistent manner.

Recording the dimensions of gastropods in shell middens can be problematic. This is due to the nature of the shell, which often requires breaking in order to remove the meat. Ethnographic evidence suggests that gastropods are often heated briefly on a fire in order to loosen the meat from the shell. The length of time in the fire varies according to the preference of the individual engaged in shellfish processing. Fishermen on the Farasan Islands were observed to leave the shellfish on the fire for anywhere between thirty seconds and ten minutes. After heating larger gastropods such as *Chicoreus sp.* are often used as improvised tools, smashing one against another to break up the shell and facilitate meat extraction. Although the consumption of smaller gastropods such as *Strombus sp.* was not observed, it is possible that a similar strategy was employed. This could be supported by the high fragmentation of shells, and their proximity to hearth deposits.

The systematic breaking of gastropods in order to remove the meat results in the vast majority of shells being incomplete, and in various states of fragmentation. Diagnostic features on these shells are therefore largely absent or incomplete. However there are two diagnostic features on gastropod shells that have survived to a greater or lesser extent. These are the apices, and outer lip. Each gastropod shell has only one apex, thus a count of apices within the sample will give an apical Minimum Number of Individual (MNI) shells in the sample. The apex can be broken off the shell; however since there is only one, no matter how small it is, can be counted.

The same is also true for the outer lip of a gastropod shell. The outer lip is a thickening of the shell between the posterior and anterior canals at the mouth of the shell (Figure 70). There is only one outer lip on the shell, but it is far more prone to fragmentation due to its position at the mouth. The outer lip is commonly defined by a thickening of the shell, which often results in the complete outer lip becoming separated from the shell intact during fragmentation. The outer lip has two diagnostic features from which it can be determined whether it is complete or not. The outer lip is defined by the posterior and anterior canals at each end; thus if these features are present the outer lip can be included in an outer lip MNI count. Incomplete specimens are omitted from the count. The outer lip also serves as an indicator of the size of the shell, since the length of the outer lip is proportional to the overall length of the gastropod (eg Dépraz *et al.* 2009). Since the vast majority of gastropod shells are fragmented this is the only measurement from which size can be calculated, and changes in size tracked through the shell mound. The outer lip MNI is almost always less than the apical MNI due to the greater exposure to damage and fragility of the outer lip. In the majority of cases the outer lip MNI values track the apical MNI at a lower value.

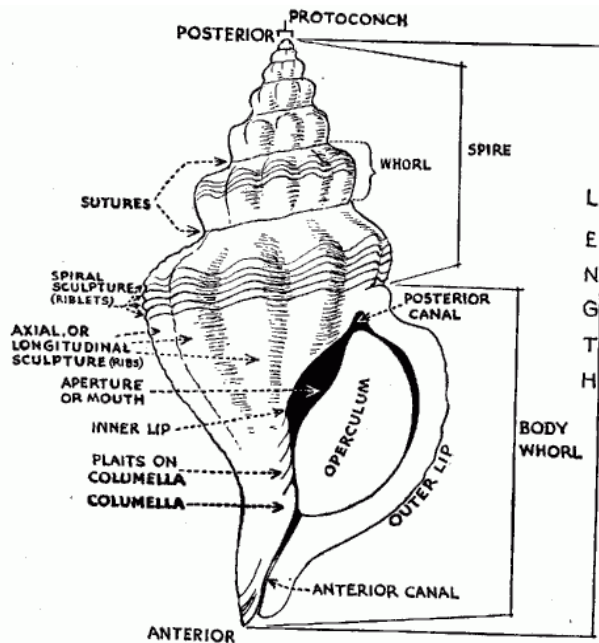


Figure 70: Gastropod apex (labelled protoconch) and outer lip (Anon, 2009).

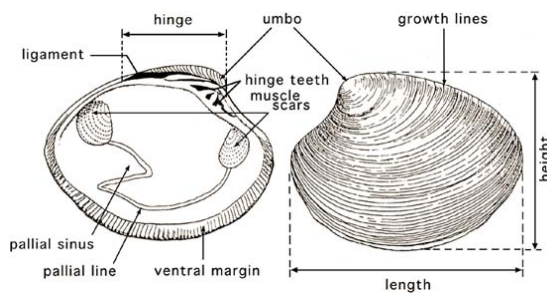


Figure 71: Bivalve shell morphology and measurements (after Helm *et al.* 2004).

Bivalves have two valves which can be analysed, resulting in two MNI values, one for each valve. Many bivalves also suffer from fragmentation, making it harder to take measurements of their size. However, the hinges of many bivalves are more robust than the rest of the shell, meaning that they are more likely to survive. From these it is possible to determine which valve the shell is (left or right valve) and to calculate the size of the shell from measuring the length of the hinge (Figure 71). The length of the hinge is proportional to the size of the shell, and also has a number of diagnostic features which allow an assessment of whether the hinge is complete or not. These features vary from species to species, however a good review can be found in Oliver (1992) "Bivalved Seashells of the Red Sea". This book was fundamental in guiding the identification of shells

from the Farasan Islands; Sharabati's "Red Sea Shells" (1984) also proved informative. In addition Oliver was visited in person, and his vast reference collection for the Red Sea consulted in order to confirm species identifications. JE0004 has a diverse range of species present with over 40 shellfish species (plus four identifiable only to taxa level).

The analysis of material from JE0004 is incomplete, of c.600kg of samples returned to York from the site only 60kg have been processed to date. The bulk samples were taken one above another in columns through the mound, with each sample relating to a specific depositional context. In this way changes in composition (and size of shellfish) could be reconstructed both vertically through the stratigraphy, and horizontally.

The main species found within the site are *Strombus fasciatus*, *Pinctada nigra*, *Plicatula plicata*, *Chama reflexa*, *Spondylus marisrubri*, *Pleuroploca trapezium*, and *Chicoreus ramosus* (Figure 72).

These species grow in a range of habitats with some overlap between a number of them. On sandy substrates *S. fasciatus* grazes on sea grass in shallow subtidal areas (other edible species such as *Anadara sp.* are also found in these habitats, but are not found in any great abundance, probably because they live within the sand and are less visible for gathering). The next range of habitats are all linked by the common theme of having a rocky substrate, with the main variable being water depth. *P. trapezium* and *C. ramosus* are predatory gastropods which roam from the exposed intertidal down to depths of c.40 and 10m respectively (both can also be found on sandy substrates but at lower concentrations, particularly for *C. ramosus*). *Pinctada nigra* and *Plicatula plicata* both occupy rocky substrates from the shallow subtidal to depths in excess of 20m. *Chama reflexa* and *Spondylus marisrubri* also inhabit rocky substrates, but at depths in excess of 5m and 2m respectively, making them more of a challenge to gather.



Figure 72: Main shellfish species found at JE0004 - *Strombus fasciatus*, *Pinctada nigra*, *Plicatula plicata*, *Chama reflexa*, *Spondylus marisrubri*, *Pleuroploca trapezium*, and *Chicoreus ramosus* (grid is 3cm; photos M. Williams).

The composition of the studies layers are expressed as a percentage by weight; there are two diagrams one including the sediment fraction (Figure 73), the other only shellfish (Figure 74). Fish bone, coral, bone, and finds from species which account for a very small percentage of the composition are grouped together into the category “Other- Species”. The vertical spacing of samples is aligned from left to right, left being the

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highest samples, right the lower. As discussed above, more than one column of bulk samples was taken which resulted in more than one sample being taken for many contexts (Figure 75).

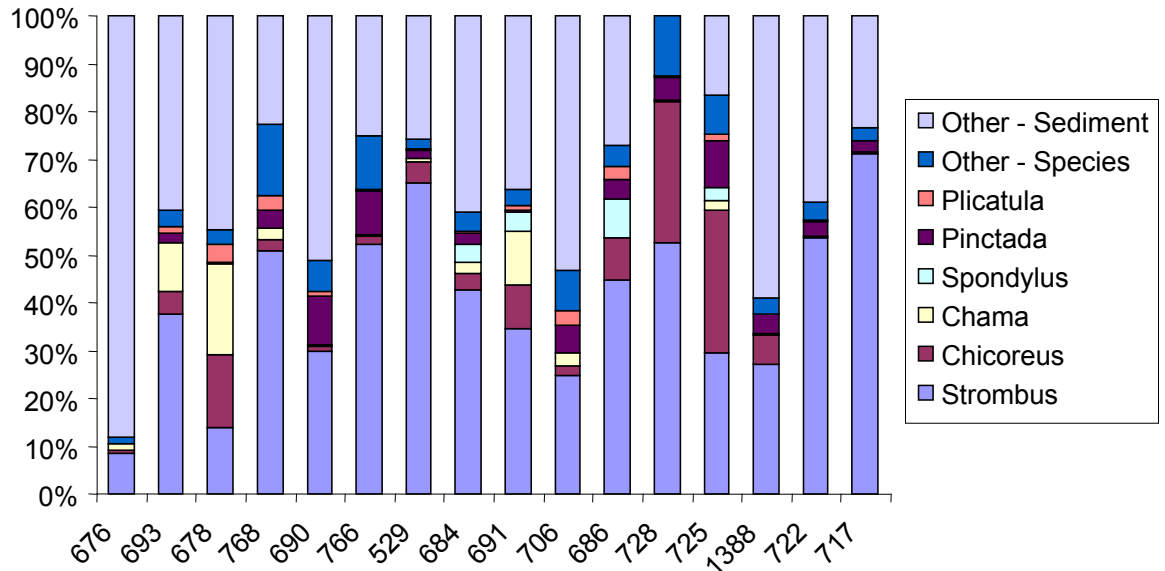


Figure 73: JE0004 composition by weight (including sediment).

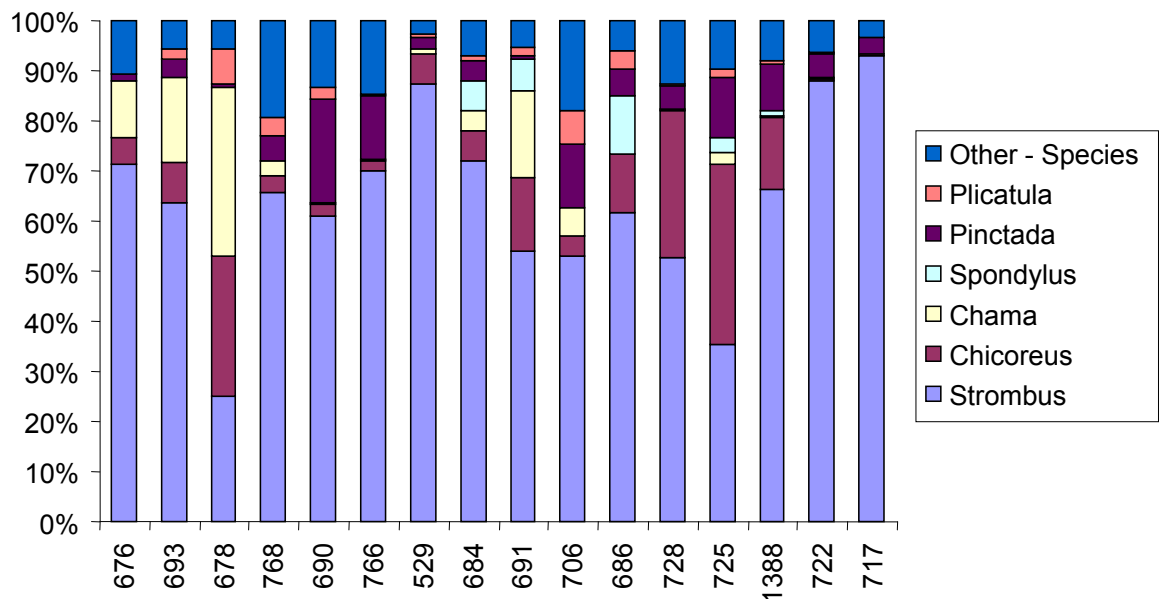


Figure 74: JE0004 percentage species composition by weight (shellfish species only).

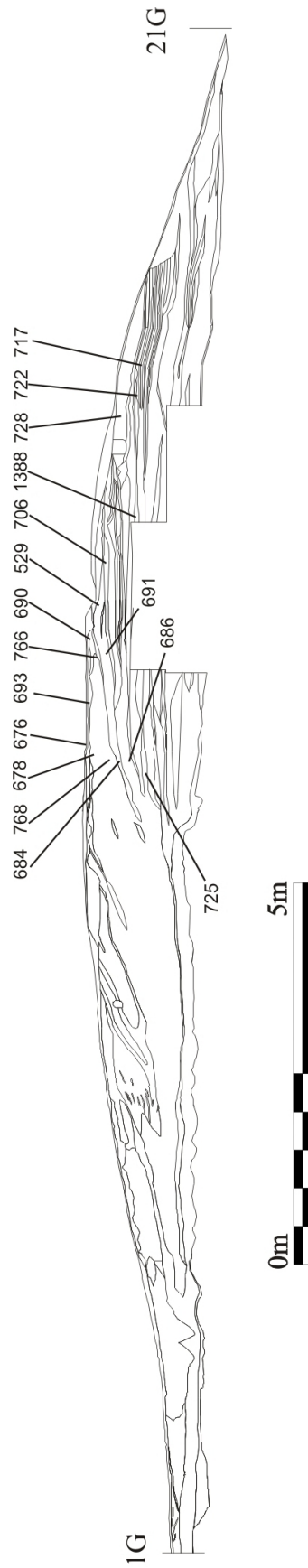


Figure 75: Location of JE0004 bulk samples in section.

The first graph clearly shows an abundance of sediment in the surface layer of the site. Whether this is to do with wind blown sediment becoming trapped in the voids between shells, or whether it is the result of repeated trampling of the surface of the mound fragmenting the shells in this layer is uncertain.

S. fasciatus is a key constituent of all analysed layers, making up over 50% except for 678 and 725. However of the two samples 678 and 768 from the same layer, the latter sample is composed of over 65% *S. fasciatus*. The spatial variation is also displayed in the samples 690/766 and 684/691 of which each pair are from the same context. The much larger discrepancy between 678 and 768 is related to the nature of this layer. The context description for this layer is that it is composed predominantly of *C. ramosus* with lenses of *S. fasciatus*. That *C. reflexa* is also present is testament to this spatial variation; when the section was exposed and being drawn and described there was little to no *C. reflexa* visible; however the bulk sample has picked up the presence of *C. reflexa*. This could be the result either of a small lens of *C. reflexa* or perhaps the constituency of the layer is changing in that direction, with *C. reflexa* playing a larger role. The nature of midden deposits is such that they are highly spatially variable, and the composition of a layer can change across a site, or have localised lenses of highly concentrated material.

There were layers which were completely devoid of *S. fasciatus*; many layers in the northern half of the mound were composed of nothing more than *C. ramosus* and *P. trapezium*. Samples 725, 686 and 678/768 were all part of this deposit; however the samples were obtained from much closer to the centre of the mound where *S. fasciatus* dominates. Samples from the northern half of the site should show this discrepancy; although samples from this area of the site have yet to be processed.

The sediments present in most of the layers were a mixture of ash, finely crushed shell, and sand. The origin of the sand is uncertain; the ash

clearly originates from hearths which would have been in existence in this part of the site. The finely crushed shell would result from trampling and processing of shell; some shells such as *P. nigra* fragment far more readily than others, such as *C. ramosus* or *C. reflexa*. However the sand is an anomaly and must have been brought to the site by some other process or for some reason other than the processing of shellfish and fish. It is possible that small amounts of sand found their way onto the site via shellfish processing or seaweed extraction; however in places sand accumulations reach 5cm thick of nearly pure sand. This was either brought up from the water deliberately or is wind blow, however the evidence is inconclusive. That it could have been washed up by waves in a storm seems unlikely, since the shell mound would have been eroded in these areas if such an event had occurred, and no evidence of this has been found in the lower layers where the sand occurs. Likewise a tsunami would have had similar destructive results. The wind can move large volumes of material such as sand, and often deposits locally thick deposits in depressions. The loose shells of a shell midden offer many small voids that can act as sand traps, contributing to the sediment composition of the site. The areas where sand forms discreet locally thick layers within the site are all on the seaward side of the mound, suggesting a consistent pattern of spatial distribution.

b) *S. fasciatus* MNI and Size

Analysis of the *S. fasciatus* shells recorded for the processed bulk samples is displayed on the following graph (Figure 76). The bar chart shows the total weight of the sample (red), the total weight of the *S. fasciatus* from that sample (blue) and the average length of the outer lip of *S. fasciatus* shells recovered from the samples (yellow). The bar chart shows the MNI values for *S. fasciatus* derived from the apices (blue) and the outer lip (red).

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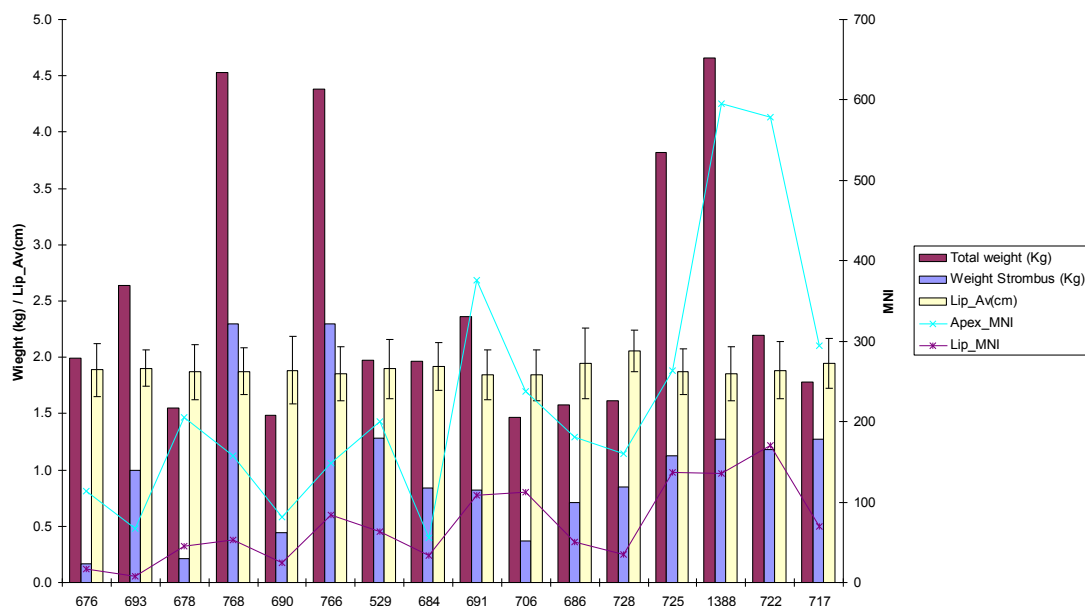


Figure 76: JE0004 *S. fasciatus* MNI, size and weight with total sample weight. Error bars for size are to two standard deviations. Sample numbers along x-axis, where upper most samples are on left through to lowest on the right.

The varying concentrations of *S. fasciatus* in each layer have already been demonstrated; however the size of *S. fasciatus* remains constant and well within the two standard deviations (giving confidence that the majority of data points fall close to the average). The most variable signal is in the MNI, which shows a general decline in both apical and outer lip MNI up the sequence.

Although these results are preliminary and many more samples need to be processed, it could tentatively be linked to shrinking species habitat or over exploitation during the final stage of vertical accumulation. This could tentatively support a social and economic change of activity in JE0004 from a *S. fasciatus* dominated assemblage to one of *C. ramosus*/*P. trapezium*. However the question still remains of why MNI does not follow the weight of *S. fasciatus* in each sample, perhaps suggesting that other factors may come into play. This could be the proximity of the sample to the centre of processing, which may have been moving over time further from the location where the samples were collected to another part of the mound. The peaks in apical MNI are likely

to be samples taken close to where the centre of processing was, where the fragile peaks were fractured off during processing.

Mark Beech undertook a brief analysis of a sample of fishbone material taken from the site and concluded that edible fish up to 10cm were present, however these were only identifiable to family level due to the nature of the remains (Table 6).

Fish bones present	Common name
<i>Myliobatidea</i>	Eagle Ray
<i>Serranidea</i>	Groupers
<i>Sparidea</i>	Sea Bream
<i>Scaridae</i>	Parrot Fish
<i>Chondrichthyes sp.</i>	Ray family

Table 6: JE0004 fish species (Beech pers. comm. 2008).

c) Scale of Shellfish Processing

The excavation has allowed an assessment of the volume of accumulated shell at JE0004 to be made. This will help to assess the scale of shellfish processing activities at the site, and to allow some further quantification of social and economic activities.

It is possible to calculate this for each layer within the site, based on the area of the context exposed in the section, and the presence or absence of a hearth. Although there are errors inherent in this technique, the hearths serve as an indicator of the centre of activities. This again is laden with assumptions; however ethnographic research and observations suggest that this is the best method with which to determine the centres of activities. This is where the deepest deposits of a context are likely to be found, thinning from the centre out towards the edge as the distance from the centre of activities increases. Where there is limited spatial movement of the hearth (and therefore centre of activities) over time deep deposits will accumulate.

This pattern has been observed both in profiles at this site and shell scatter sites display a similar distribution. Despite these observations there still remains an element of uncertainty with these calculations. This is especially relevant to the northern deposits which do not have hearths within them, whilst the hearths on the coastal side are restricted to a c.6m area. However the depth and shape of the deposits exposed allow a rough assessment of the size and nature of each depositional event.

The volume of each context has been calculated using the assumption that the deposits exposed in the section represent the deepest part of the context. Although this assumption is basic, even for those contexts where a hearth is present, it gives a minimum estimation of the thickness of the deposit. The calculation used to assess the depth of the deposits is based on modelling each layer as a truncated cone with a circular base. Despite the assumptions in the calculation this method gives a good rough estimate which can be applied to the deposits. The area of each layer in the exposed section was recorded and the measurements used in the calculations (Figure 77). Another variable is the topography of the bedrock under the shell mound, especially the unexcavated areas, which will affect the thickness of the overlying layers.

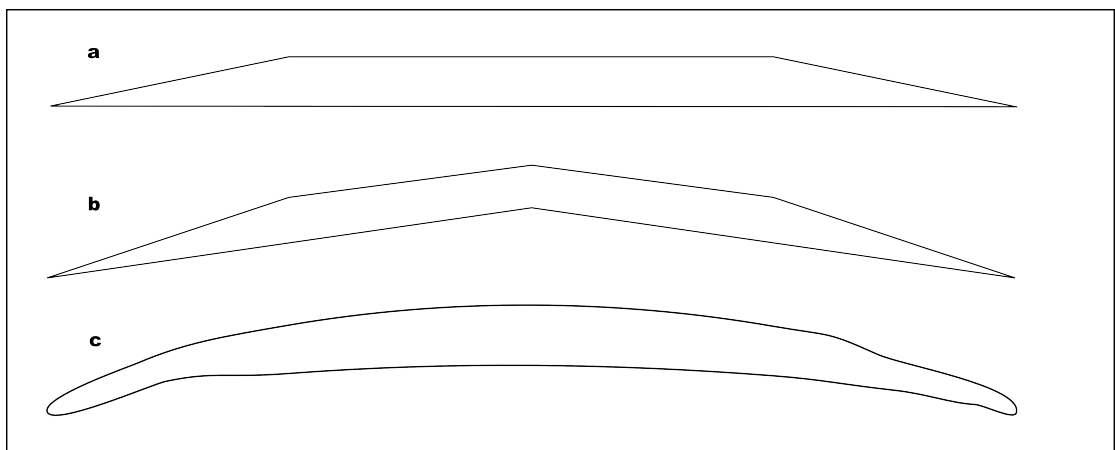


Figure 77: Calculating the volume of a layer from section from cross section area. a – cross section of a truncated cone; b – how the cross section compares to c. a generalised cross section of a layer.

The only true estimate of volume/area for a deposit is one derived from an open excavation, where all of the deposits are exposed, measured

and recorded. In testing the calculations described above most commonly resulted in an underestimation of the total volume of a layer, however due to the highly variable nature of the stratigraphy the results can only be taken as a rough guide. Many deposits will not be circular, and will more likely be elliptical due to people not wanting to sit down wind of a fire (where the smoke blows; eg Binford 1978). There may also be discrepancies in the seating position of the people about the campfire, and even in the activities which they were undertaking which will result in the depositional record diverging from the standard models (eg Binford 1978).

The total volume of material excavated over three seasons of field work is 12.6m^3 , with the transverse trench on the north side of the mound accounting for 8.8m^3 . This compares to an estimated total volume for the mound of 275m^3 . In order to complete the transverse trench to bedrock through the full length of the mound there is a remaining 1.3m^3 of shell midden to excavate, however this is through the deepest part of the site, and requires careful excavation in order to minimise the potential of section collapse. In addition to this, the implementation of single context planning requires that each layer be excavated and recorded, slowing the process down further. Between seasons excavations were back filled to ensure stability and integrity of the site.

The volume of each excavated layer has been calculated in order to estimate the composition of the mound. The total volume for these calculations is 228.5m^3 . Although this figure is much lower than estimate for the entire mound, it does not account for the unexcavated section in the centre of the transverse trench. There are also variations in the shape of the mound which account for a greater volume.

The composition of the excavated area of the mound allowed the relative composition of the mound to be determined; this can be expressed in terms of weight or volume as shown in the following calculations . However the shell constituent is broadly equivalent to 1000kg per cubic

meter, with some variations depending on the degree of fragmentation and size of shell and matrix.

Using volume alone it is clear to see that *C. ramosus* and *P. trapezium* make up the majority of the volume of the excavated material (Figure 78). The extrapolated values for the entire mound are consistent with these figures. *S. fasciatus* is the next greatest constituent, followed by the sediment fraction of silts and sands. However, distinguishing between silts/sands and ash is complicated, and they are often mixed together; it is therefore useful to view these two side by side. The lesser three constituents by volume are *C. reflexa* and *S. marisrubri*, *P. nigra*, and the charcoal component.

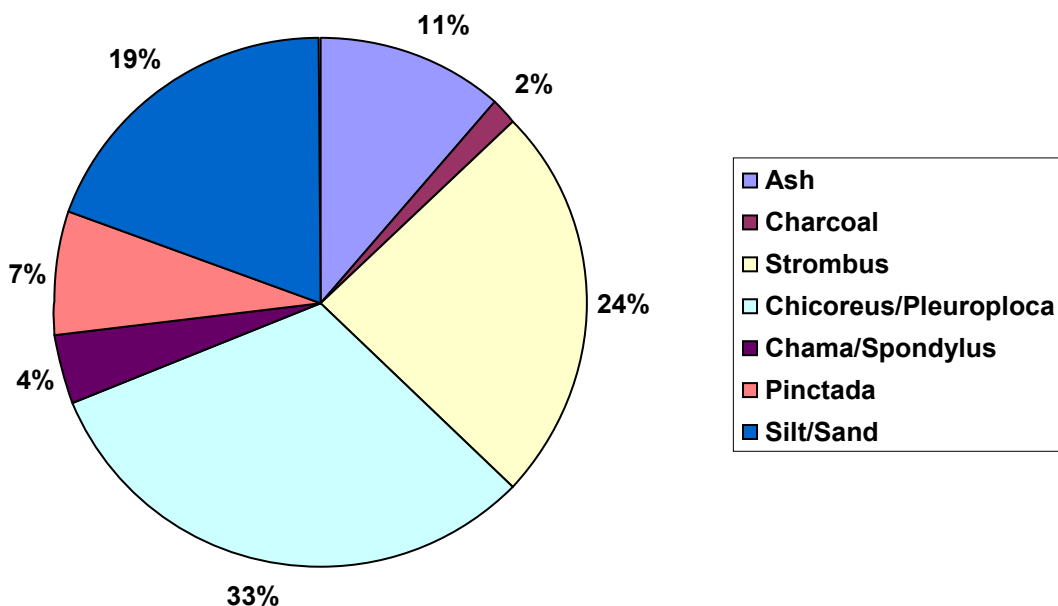


Figure 78: Percentage species composition (by volume) for JE0004. Calculated from excavated areas.

The *S. fasciatus* and *C. Ramosus/P. trapezium* component show the clear reliance on the shallow subtidal habitats which are dominant immediately offshore of the site. The two groups also highlight the two contrasting settings, of sandy and rocky substrate environments. The fact that the large murex shells occupy a larger volume, and result in voids between their shells due to their spiny nature might be seen to skew the results. However their larger size and robust shells also mean that their density is comparable to that of other shells such as *S. fasciatus*.

The silt/sand and ash fractions are large, over a quarter of the volume. Much of this material is loose, contributing similar weights as the shell. The ash and charcoal indicate that significant episodes of burning were taking place on the coastal side of the site.

The final two constituents, *P. nigra* and *C. reflexa*/*S. marisrubri* appear to play a much smaller part in the composition of the site, and this is perhaps not surprising when considering that these species are found at greater depth, and therefore require diving to gather. *P. nigra* shells fragment readily, and often form dense layers in the mound.

The volume of the mound is approximately 275m³; these calculations are based on the data obtained from surveying and excavating the site. This value differs from that which would be obtained if the survey observation data and calculations had been used; these gave a value of 228.5m³. The discrepancy encountered is largely a product of the way that the two values were reached. The detailed survey and excavation of the site resulted in a much more accurate evaluation taking account of the shape and variations in the mound. Calculations of shell mound volumes derived from the survey data are less accurate than those calculated from the excavation data. This is because the survey calculations cannot account for local variations at the site (such as uneven bedrock beneath the site), and apply the truncated cone model to each site in a blanket approach. Although this will always result in inaccuracies such it provides a good conservative estimate for mound volume.

5.3.4 Section Summary

Site JE0004 has a very interesting stratigraphy showing that there were two distinct formation processes at work in two successive phases. This is associated with a shift in the social and economic activities at the site. The analysis of *S. fasciatus* suggests that the MNI was reducing over time. This could be related to movements of the hearth and relocation of centres of processing. However it could be evidence of local

environmental change resulting in a decrease in the availability of *S. fasciatus*, which ultimately resulted in a change of primary target species and change in formation processes at the site.

The site is a home base with numerous activities focused on coastal resource exploitation. Intensive shellfish processing is the most archaeologically visible of these, although dating is needed to quantify this.

5.4.1 KM1057 Results

The second site selected for excavation is in the Khur Maadi, KM1057. It is one of a pair of sites that are the largest of the group and occupy a central location. They are positioned at the junction between the former open coastline, and the Khur Maadi bay (Figure 79). The distribution of shell sites in this area also changes, from a predominantly linear distribution along the open coastline, to a more dispersed distribution along the interior of the bay. The site was first identified in 2006 as part of the survey; it was revisited in 2008 and the potential for excavation recognised. This site offers a different environmental setting to JE0004, being located next to a small bay. KM1057 will allow an assessment of the processes at work within a mound, and the rates of formation. It will also allow an assessment of the social and economic activities at the site, and responses to environmental change.

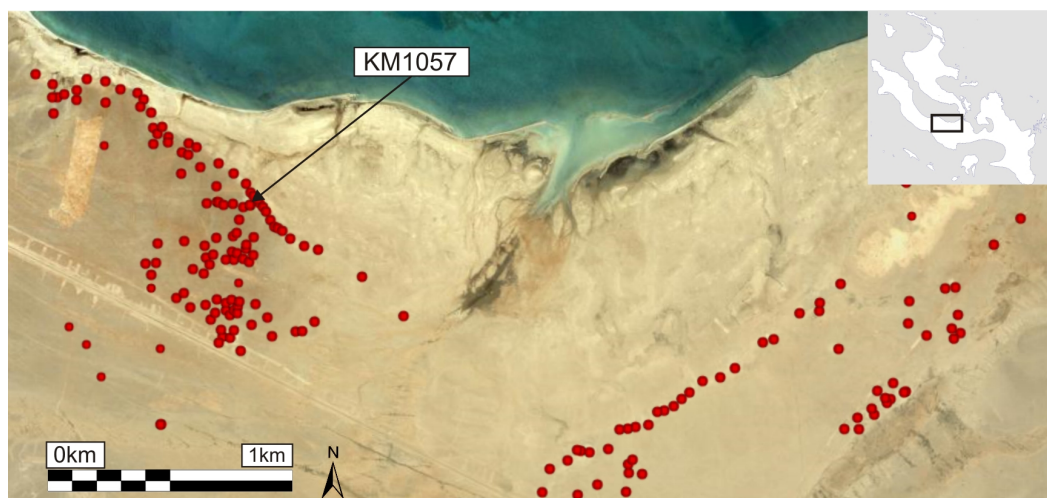


Figure 79: Location of KM1057; red dots are shell sites.

Site KM1057 has been badly damaged by bulldozing activity to remove material for the building industry, exposing a section through the deepest part of the mound at the centre, making it ideal for this study. A large number of sites within the group had also been badly damaged, with extensive extraction activity taking place to remove the shell for building material (Figure 80). Roughly two thirds of the total volume of KM1057 has been removed, leaving two steep sections through the deepest part of the mound. This was exploited, and a meter wide section cleaned through the centre of the mound at its deepest point (Figure 81 and 82).



Figure 80: Damage to site KM1057; KM1055 visible in the background is untouched (photo H Robson).

The objective was to expose a continuous section through the deepest part of the mound to bedrock in order to better understand the stratigraphy of the site and obtain samples for dating and composition analysis. However it was only possible to expose a 1m wide section through the mound as the loose shell was highly unstable, and the section needed to be stepped back in two places to increase stability.

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It was not necessary to create a grid system for this site due to the limited nature of the section; instead the site was planned and section drawn once exposed.

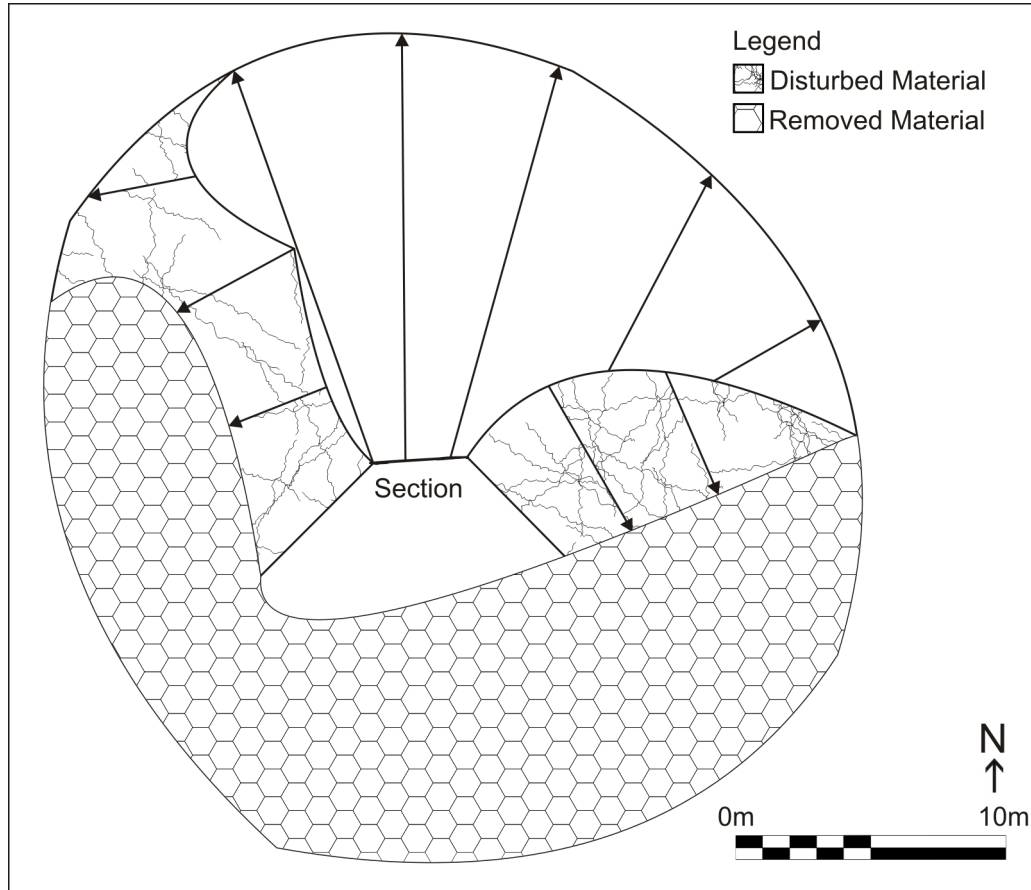


Figure 81: Plan of site KM1057. Arrows indicate direction of slope.

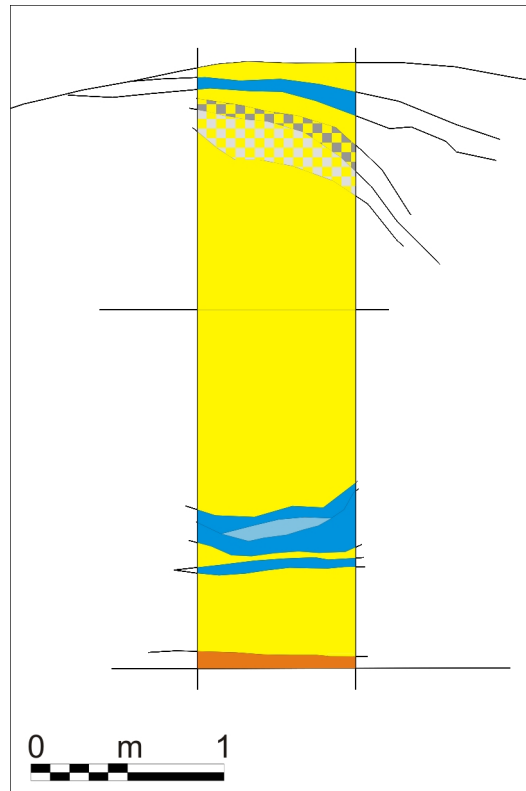


Figure 82: East facing section drawing of KM1057. Yellow is *S. fasciatus*, grey is ash, blue *C. reflexa*/*S. marisrubri* and orange is *terra rosa* sediment over bedrock.

The section revealed a relatively homogeneous structure through the three meter deep mound, composed almost entirely of *S. fasciatus*. There were two exceptions to this, near the top and base of the mound, where layers of *C. reflexa*/*S. marisrubri* interrupted the sequence. In total there are twelve different contexts within the mound, five of clean *S. fasciatus*, two of *S. fasciatus* and ash, five of *C. reflexa*/*S. marisrubri* and one basal layer of brown silt.

The excavation achieved a section to bedrock through the deepest part of the mound (Figure 83); however it was limited to 1m wide due to the instability of the shell material. A column of bulk samples was taken through the mound, one for each context, where the contexts were deeper than 10cm one sample was taken every 10cm.



Figure 83: Excavating a section into KM1057 (photo M. Williams).

5.4.2 Reconstructing the formation processes of KM1057

The limited nature of the section and lack of complex stratigraphy makes it hard to reconstruct the process of formation. However it is likely this site originated from a single point close to the centre of the site, and accumulated via vertical accumulation with horizontal growth, as indicated by the upper layers of the site.

5.4.3 Social And Economic Processes Behind Site Formation At KM1057

a) Site Composition

The composition of the bulk samples closely mirrored the observed section, both in terms of species and sediment components (Figure 84). In the samples corresponding to the ashy layers there is a greater concentration of sediment, up to 50%. The composition by weight also shows the dominance of *S. fasciatus* through the mound.

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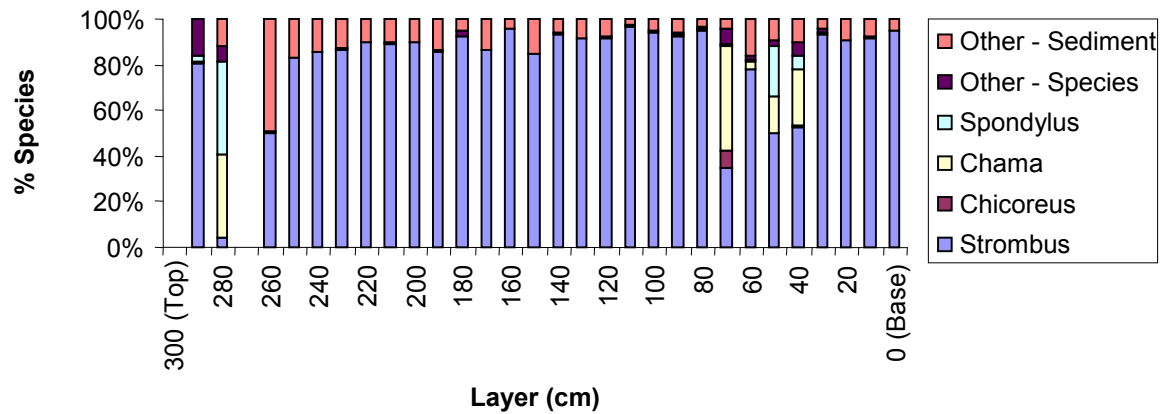


Figure 84: Composition by weight for KM1057 (where other – sediment refers to sediments of all sizes).

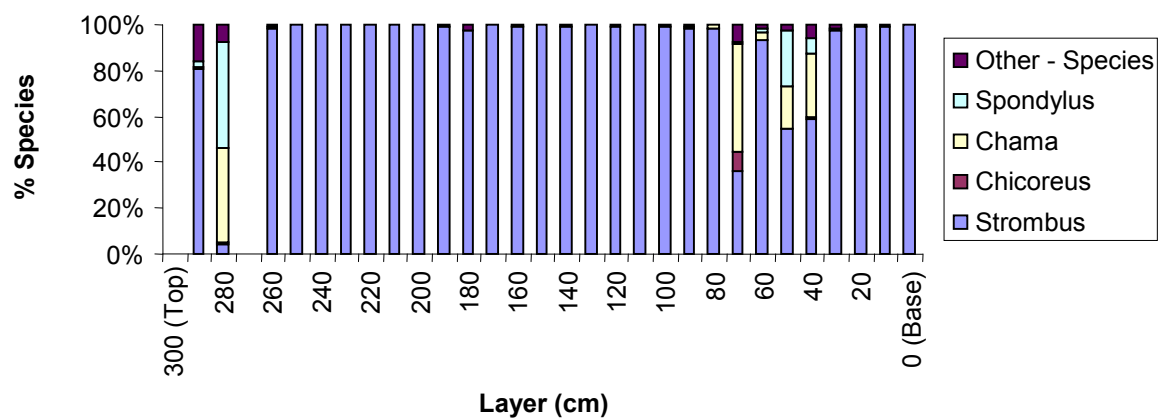


Figure 85: Species composition by weight without sediment for KM1057.

When the sediment component is taken out, the dominance of *S. fasciatus* as the species of choice is even more apparent (Figure 85). The exceptions to this are the *C. reflexa*/*S. marisrubri* layers and ash layer already described which show up very clearly. The presence of *C. ramosus* also becomes apparent, present in background numbers for the majority of the section, but occurring in slightly greater concentrations in association with the *C. reflexa*/*S. marisrubri* layers, and close to the surface.

Extrapolating this data for the entire site gives a dominant proportion of *S. fasciatus* of 81% (Figure 86). The composition suggests that this site was dedicated almost entirely to processing *S. fasciatus* with very few other activities taking place.

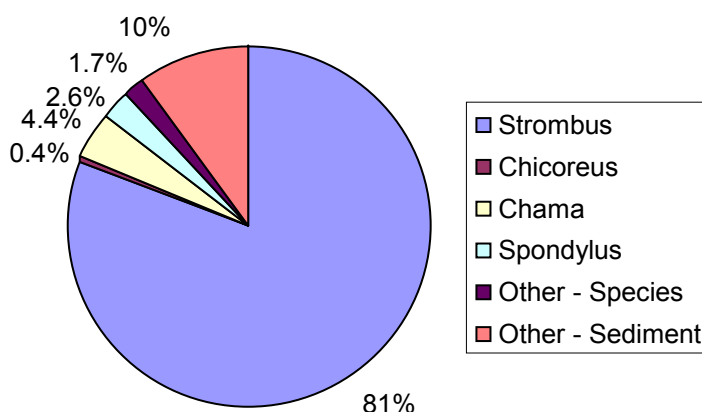


Figure 86: Cumulative composition by weight for KM1057 extrapolated from excavated contexts (where other – sediment refers to sediments of all sizes).

b) *S. fasciatus* MNI and Size

Work undertaken by Eva Laurie and the author (in the same manner as for JE0004) has shown that there is little variation in the size of the *S. fasciatus* shells throughout the sequence, with the exception of a small decrease in size in the centre of profile which quickly recovers (Figure 87). With the exception of the smaller sizes recorded in the middle of the stratigraphy the data show that the shell beds in the Khur Maadi bay were stable, and that shellfish were collected when they reached their prime size. They also show that despite high intensity exploitation the shellfish still reached maximum size (with the exception of the middle period). The period of slightly smaller shell size could be a result of a period of more intense exploitation, when the shellfish were harvested before they reached prime size. However the size recovered following the decline, suggesting that either the intensification of exploitation decreased or that the decrease in shell size was due to some other environmental factor which was a short lived episode. The direct cause will require further investigation – both a better understanding of the chronology of the site and surrounding sites (such as accumulation rates), and testing on the shells to establish whether there were any changes in the environment in which the shellfish were growing.

Analysis of the bulk samples from KM1057 followed the same procedures as for JE0004, with MNI and shell sizes being calculated.

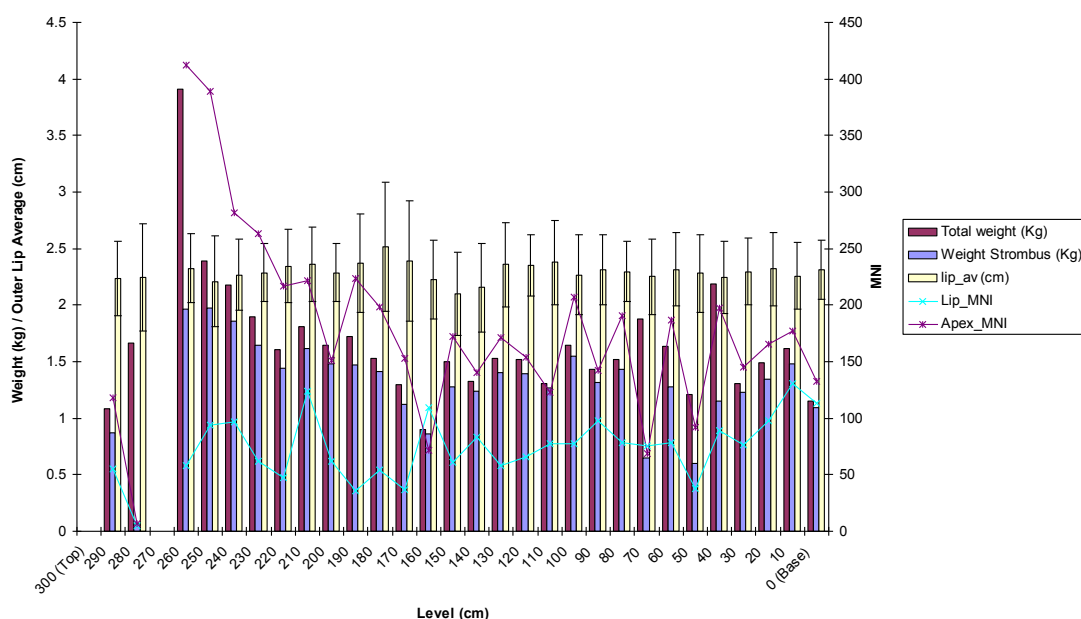


Figure 87: Apex MNI and Outer Lip MNI and Average Size of *S. fasciatus* for KM105. Bars = outer lip average size; Blue line = Apex MNI; Yellow line = Outer Lip MNI.

The size of *S. fasciatus* is consistently larger than at JE0004, perhaps owing to the more sheltered environment of the bay allowing greater habitat stability. Although there are some small variations in shell size it does not deviate beyond two standard deviations.

As in JE0004 the MNI derived from the outer lip follows the apical MNI. There are exceptions to the relationship; there are four samples where apical MNI drops and outer lip MNI rises. In two of these cases the outer lip MNI exceeds the apical MNI. One of these samples is dominated by *C. reflexa*, perhaps resulting in smaller fragmented apices moving down the section through the larger gaps between the *C. reflexa* shells. This is not the case for the other four samples which are dominated by *S. fasciatus*. Several other contexts near the top of the sequence display highly elevated apical MNI values, which is not mirrored by outer lip MNI. These contexts are associated with much higher levels of sediment, notably ash.

The most likely explanation is that the bulk samples are highly localised samples, and that these are micro-variations within the deposit. Perhaps during these phases of deposition the location of processing was further away, resulting in fewer apices reaching this area, since they are more likely to drop about the centre of processing due to their small nature and the fact that they are most likely to break off during processing. Certainly during these two events the size of the *S. fasciatus* does not vary considerably.

The apical MNI data show a broad agreement with the weight of *S. fasciatus* within the samples, with the exception of the peak at 260-270cm. This suggests that broadly speaking the apical MNI is an accurate representation of the number of individual *S. fasciatus* shells within the sample. The peak in apical MNI is problematic, but could represent a focus of activity around a hearth.

c) Scale of Shellfish Processing

Using the same method as for JE0004 to extrapolate the volume of each layer to get a value for the whole site is not as robust for KM1057. This is because the exposed section did not reveal the full cross-sectional extent of each layer. However the previous data suggests that this site was dedicated to intensive shellfish processing.

5.4.4 Section Summary

The stratigraphy of KM1057 is not as complicated as JE0004, however it is no less interesting. It demonstrates a different formation process dominated by the intensive processing of predominantly *S. fasciatus*. The lack of hearths and focus on a single species makes this site stand out as a specific processing site.

The next question is to determine how fast the site accumulated, since the clean nature of the deposits suggest that it was very rapid. There is

also the important question of where the home-base sites are located; if indeed they exist in this group of sites.

5.5 Chapter Summary

This chapter has succeeded in reconstructing the formation processes of the two excavated shell mounds. Both suggest intensive shellfish processing via two different social and economic sets of processes. These need quantifying by dating the stratigraphy of the sites. The relationship of these two sites with other sites in their group is also necessary in order to determine the intensity of exploitation. The sites show evidence of responses to local geomorphological change, linkages between the two will need investigating.

Chapter 6

Spatial Relationships of Shell Mound Building Activity

6.1 Introduction

The previous chapter investigated the formation processes and underlying social and economic processes at work in two key shell mound sites, through excavation. To link these two sites to other shell mounds in their respective groups would require further excavation of surrounding sites. This would allow an assessment of the formation processes, composition and rates of formation of the additional sites in order to determine similarities or differences between sites and groups of sites. Large-scale excavation is costly therefore test pitting offered the best method to investigate these relationships. The drawback of this technique is that it does not open up a large enough section to be able to fully assess the formation processes of the site; rather it only gives a brief snap-shot. Likewise any dating samples recovered will only date the deposits from the test pit, missing earlier or later deposits depending on where the samples are taken from. However this can inform on the social and economic activities at work at the site, and help to determine relationships between sites at a range of scales.

This section will present the results of the test pitting program, which focused on three key shell midden groups: Janaba East, Janaba West, and Khur Maadi, with two further groups Southern Saqid and Qumah covered in less detail.

6.2 Method

Test pitting is vital in gaining a basic understanding of the activities stratigraphy, composition and activities at a site. This will often be the final deposits of the site, and therefore sediments representing the final stages or abandonment of the site. However taphonomic processes can result in truncation of a deposit such as deflation or other forms of erosion, meaning that the upper most deposits may be lost; without a full stratigraphy it is often hard to assess this. This should not detract from

6. Spatial Relationships of Shell Mound Building Activity

the method which gives an excellent idea of the site stratigraphy and composition, and therefore a guide to activities carried out at the site.

The test pitting methodology followed a standard procedure (with the exception of Qumah Bay which will be discussed further on). This involved selecting a representative series of mounds within a group for investigation, in order to obtain a representative sample, as it was impractical to test pit all sites. The aim of the test pits, as mentioned above, was to determine a snapshot of the stratigraphy and composition of the site(s) and retrieve bulk and dating samples from each test pit in order to further the understanding of each site. Once the sites had been selected they were sampled by excavating a 50cm³ test pit (or step trench depending on the shape of the site) close to the top of the mound (Figure 88). Where scatters were sampled the test pit was excavated close to the centre of the site. In some cases it was deemed necessary to excavate a second test pit lower down the side of the mound. This was commonly where the surface composition of the site changed drastically and it was desirable to investigate both areas of the site.



Figure 88: An example of a test pit, in this case JW1841 (photo H. Robson).

6. Spatial Relationships of Shell Mound Building Activity

Once the test pit was opened a section was cleaned and recorded, before bulk and dating samples were removed following the same conventions as for excavation. After this the protocol was for excavations to be back filled.

6.3 Janaba East Test Pits

Three of the smaller shell middens adjacent to the excavated site of JE0004 were test pitted in order to determine their relationship via composition and internal structure. As already described, JE0004 is the largest and most prominently located shell site within a group of eight shell middens along this section of coast. Test pitting activity was therefore focused on a number of the shell mound peripheral to this site.

Test pits were excavated in JE0001, JE0002 and JE0003 to the east of JE0004 (Figure 89). Where the deposits allowed the test pits exposed sections up to 50cm deep, and a meter long. Shell scatters were also present along this section of coastline however these were not test pitted either due to disturbance or the very thin nature of the deposits. Shell scatters JE1623, JE1624 and JE1625 were heavily disturbed by waste material from the power station complex, whilst JE1626 was very limited in nature with very thin deposits.

6. Spatial Relationships of Shell Mound Building Activity



Figure 89: Location of Janaba East test pits.

Exposed sections were recorded and bulk samples of 1-2kg were taken from each trench.

The composition of the sites was broadly consistent with that of JE0004. The stratigraphy of site JE0002 showed close similarities, being stratified with similar constituent species to JE0004 (Figure 90). The association of certain species together was present in JE0002; the structure even shows development of the mound through vertical accumulation (Russo and Heide 2003), similar to the final phases of JE0004. The nature and extent of JE0001 and JE0003 were of a more restricted nature and composed predominantly of *S. fasciatus*.

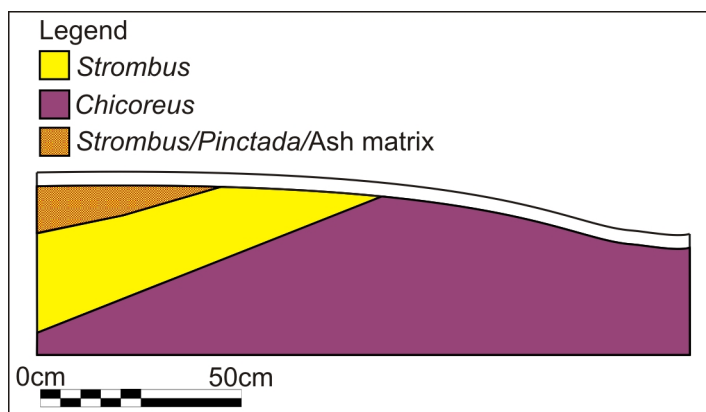


Figure 90: West facing section drawings from JE0002 test pit.

6.4 Khur Maadi Test Pits

Test pits were excavated into 16 shell sites in the Khur Maadi group. There are 112 sites in this group, to test pit them all would have been impractical. Therefore a number of sites were selected in order to gain a representative sample. There are two shell mounds of roughly equal size which are the largest of the group; they are located in close proximity to one another, close to the centre of a wide distribution of sites which marks the western transition into the former Khur Maadi Bay. The decision was therefore taken to sample a number of sites along a transect running roughly north-south (Figure 91). The transect would be aligned to intersect the excavated site KM1057, but would also be flexible in order to take in as many and varied sites as possible. This would allow a representative sample to be taken from the more linearly distributed sites in the north to the more widely distributed sites in the south. This would serve not only as a comparison for sites to KM1057 but to show if there was any variation between sites from the north and south of this area.

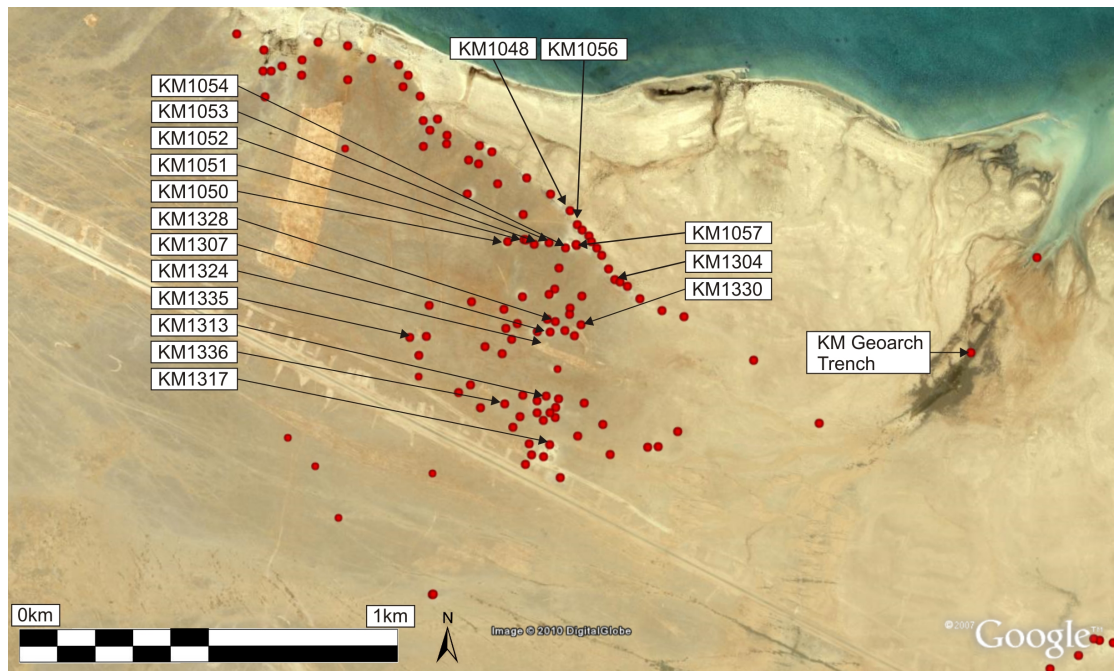


Figure 91: Khur Maadi location of test pits with site numbers. Red dots indicate sites. Note KM1057 is excavated site.

6. Spatial Relationships of Shell Mound Building Activity

Test pits into the sites revealed two different configurations of composition with sites either dominated solely by *S. fasciatus* or composed of a mixture of *C. reflexa* and *S. marisrubri*. This is highlighted by the external appearance of shell mounds in the area, either having a white or dark appearance respectively. Many of the observed sites showed the presence of both components, notably site KM1015 (Figure 92) which correlates with the toss/drop zone model. Many of the sites are visibly different colours, being dark at one end and light at the other. There are two possible scenarios that could explain this. The first is that the distribution of shells in a site represents depositional trends – perhaps reflecting the “toss/drop” model of sites KM1015 and JE0004. However, some sites appear to be almost completely dominated by one or the other – such as KM1057 and its sister site. The second possibility is that these differences represent different activities at each site, whereby one shellfish species is almost exclusively processed at the site.



Figure 92: KM1015 showing darker outer ring around lighter coloured centre. Darker outer ring is composed of *C. reflexa*/*S. marisrubri*; lighter centre is composed of *S. fasciatus*. (Photo G. Bailey).

6. Spatial Relationships of Shell Mound Building Activity

The test pitting activity in the Khur Maadi was carried out in two phases; five test pits were excavated in 2008 into sites, a further eleven were excavated in 2009, bringing the total to 16 sites (Figure 91).

The results from these test pits reflect the surface observations, with some sites containing a majority of *S. fasciatus*, some a majority of *C. reflexa*/*S. marisrubri*, and the rest being a mixture of the two (Table 7). It is interesting to note that *C. ramosus* is present in most sites, usually as a lesser component. Other species are also present in most sites, although again at consistently lower concentrations.

6. Spatial Relationships of Shell Mound Building Activity

Site	Chic.	Pleur.	Chama	Plica.	Str. tri.	Arca	Strom.	Spon.	Tibia	Ana.	Conus	Pinct.
KM1056	-		+	√	-	-	√	+	-			
KM1304							+					
KM1307	-		√				+	√	-			
KM1313 Upper	-	-	√		-		+	√		-		
KM1313 Lower	-	-			-		+					
KM1317			√				+	√				
KM1324	-		-	-		-	+	-	-			
KM1328	√	√	√	-	-	-	+					
KM1330	√		+		-	-	-	+	-			
KM1335	-		-			-	+		-			
KM1336	√		√		-			√	-			
KM1048	-		+		-		-	+				
KM1050							+					
KM1051	√		√				√	√				
KM1052	√		√				√	√				
KM1053	√		√			-	√	√			-	-
KM1054							+					

Table 7: Khur Maadi test pit composition. Key: “-” low concentrations; “√” present in moderate quantities; “+” dominates assemblage. *Chic.* = *C. ramosus*, *Pleur.* = *P. trapezium*, *Plica.* = *Plicatula plicata*, *Str. tri.* = *Strombus tricornus*, *Strom.* = *Strombus*, *Spon.* = *S. marisrubri*, *Ana.* = *Anadara*, *Pinct.* = *Pinctada nigra*.

6.5 Janaba West Test Pits

During the 2009 field season the west bank of Janaba Bay West (JW) was identified as a priority for research because an airport is planned for the area. Many of the sites along this stretch of palaeo-coastline are large shell mounds, with no single mounds dominating in terms of size or location. The mounds are predominantly distributed linearly, and sites in the centre of the group are generally larger than those at either end. This demonstrates that groups of shell mounds are not always dominated by the emergence of a single large shell mound, even when the size of sites can be quite substantial. The decision was therefore taken to undertake a test-pitting program into a range of these sites in order to obtain more information about the sites before access to them is restricted or they are destroyed.

Test pits were excavated into 21 of the sites along this section the palaeocoastline using a regular sampling strategy of every fourth site (Figure 93). The test pits revealed well stratified deposits, containing similar constituents to the sites in KM and JE. Some test pits revealed a predominance of *S. fasciatus* in the upper most 50cm of the sites. Layers of clean crushed *S. fasciatus* were found in most sites, however it was also found in association with layers of ash; *C. ramosus* was found in all sites, and a combination of *C. reflexa* and *S. marisrubri* was found at most sites. Layers with an ashy matrix were also common.

6. Spatial Relationships of Shell Mound Building Activity

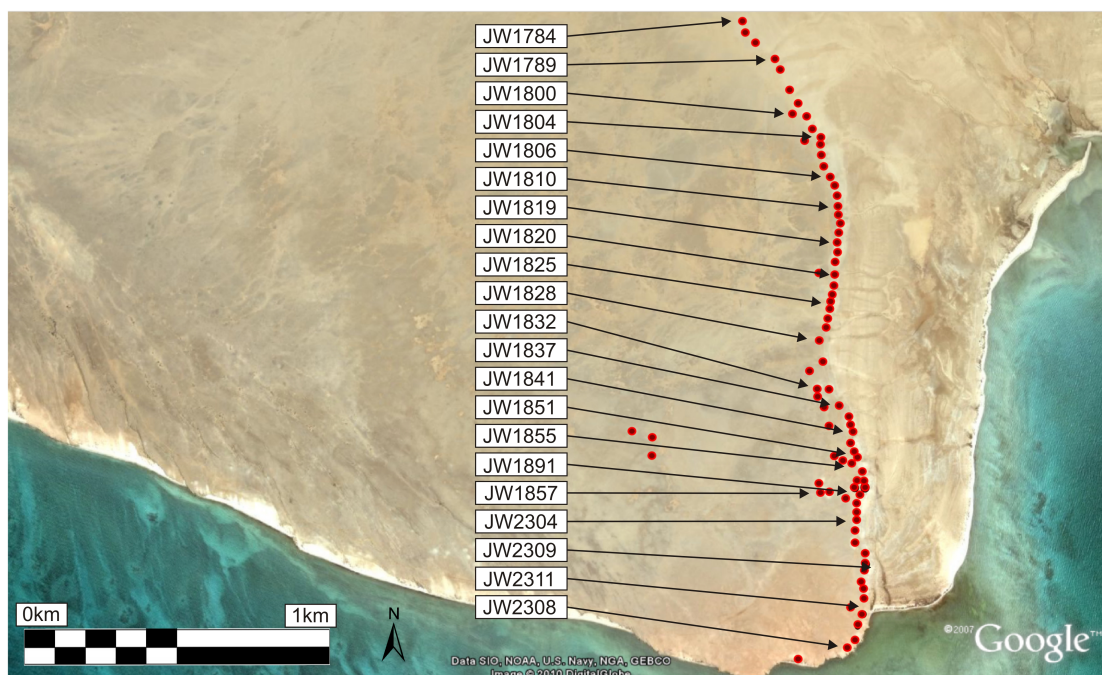


Figure 93: Janaba West test pit locations.

Desicated roots were present in the stratigraphies of a number of sites, suggesting periods of stability and/or moisture availability. Sites JW1825 had roots present 20cm below the surface; site JW1832 also had roots present at 12cm and 24cm; and site JW1087 had roots at 9cm and 32cm. This would suggest that the mounds were unoccupied for long enough for vegetation to establish on their surface, before reoccupation and further shell accumulation. There are several possible scenarios which could explain this, although further investigation would be needed to test them. It might be that the site was unoccupied for an extended period, allowing vegetation to become established. However plants can quickly take root in areas of a site which are not being actively used, meaning that temporary abandonment of the site is not necessary.

Mound JW1837 had a coral structure on top of it. This was constructed of cut, square, coral blocks, aligned in a rectangle. The coral blocks had been sunk into the surface of the mound to promote stability in their upright position. On the surface of the mound pottery was found, and a basalt flake. No pottery was found below the surface of the mound, in the test pit. The hypothesis is that the coral blocks are a secondary use of the site, after deposition of

6. Spatial Relationships of Shell Mound Building Activity

shellfish had terminated. The same hypothesis is thought to apply to the pottery, although whether the pottery is associated with the coral structure or not is open to debate, since the surface of the site is clearly part of a complicated palimpsest.

The vast majority of the test pits revealed *S. fasciatus* dominated assemblages, with *P. nigra* also playing a significant role at many sites, and dominating a couple (Table 8). *C. reflexa* was present at a number of sites, although in much lower frequencies and concentrations than in other groups, similarly with *S. marisrubri*. This is perhaps a manifestation of the greater distance to the deeper water environments where these species grow. *C. ramosus* and *P. trapezium* were present in over half of the sites, with *Barbatia setigera* the only other shellfish present in notable quantities.

6. Spatial Relationships of Shell Mound Building Activity

Site	Chic.	Pleur.	Chama	Str. tri.	Strom.	Spon.	Pinct.	Conus	Barb.	Ana.	Plic.
JW1784	-		-	--	+		+		-		
JW1789	-				-		+				
JW1800	-		✓		✓+		+		-		
JW1804					+						
JW1806	-				+		+				
JW1810	-		-	-	+		✓				-
JW1819	✓		✓	-	✓	-			-	-	-
JW1820	-	-	-		+		+		-		-
JW1825	-		✓		+						
JW1828					+						
JW1832			-		+		-		-		-
JW1837					+						
JW1841					+		✓		✓		
JW1851	✓	-	-	✓	+	-	+		✓		-
JW1855	-		✓	-	✓			-	✓	-	
JW1857			-		+		✓				
JW1891		-		-	+						
JW1083					+		-				
JW1087	-	-	-		+				-		
JW0126	-		-		+						
JW1100			-		✓		+		✓		

Table 8: Janaba West test pit composition. Key: “-” low concentrations; “✓” present in moderate quantities; “+” dominates assemblage. *Barb.* = *Barbatia setigera*.

6. Spatial Relationships of Shell Mound Building Activity

The test pits showed that the sites have a varied composition. The majority of sites excavated demonstrated a composition of *S. fasciatus*, *C. reflexa*, *C. ramosus* and *P. trapezium*, with *S. marisrubri* present in lower concentrations where *C. reflexa* was present. Some of the test pits showed a composition of pure *S. fasciatus*. *Arca avellana* was present in greater concentrations at the more northerly sites, particularly the scatters at the head of the formation. However it was also present through many of the mounds to the south. The composition of sites indicates that two different environments were being exploited – shallow waters, both sandy and rocky substrates, and deeper coral substrates.

Evidence of hearths (high concentrations of ash) was also found in two test pits, however the size of the test pits was insufficient to determine the extent of these, or whether any were present at the other sites.

6.6 Qumah Island and Bay Dating Samples

The new airport will also have implications for the island of Qumah as the island could be under the flight path and therefore be off limits. Some stretches of the coastline are inaccessible by vehicles due to the rough terrain, and the presence of only one or two working vehicles on the island. The decision was taken to fully survey all of the coastlines of the island, either by foot or vehicle. Due to the climate and remoteness it was impractical to carry excavation tools to excavate test pits. A small pick and trowel were taken in order to procure dating samples, and the surface composition of the sites was noted. *S. fasciatus*, *C. reflexa*, *S. marisrubri*, and *C. reflexa* were all common constituents of the majority of mounds, but it is not possible to speculate further on the composition or the stratigraphy of the sites. Sixteen dating samples were recovered from as many sites (Figure 94).

6. Spatial Relationships of Shell Mound Building Activity

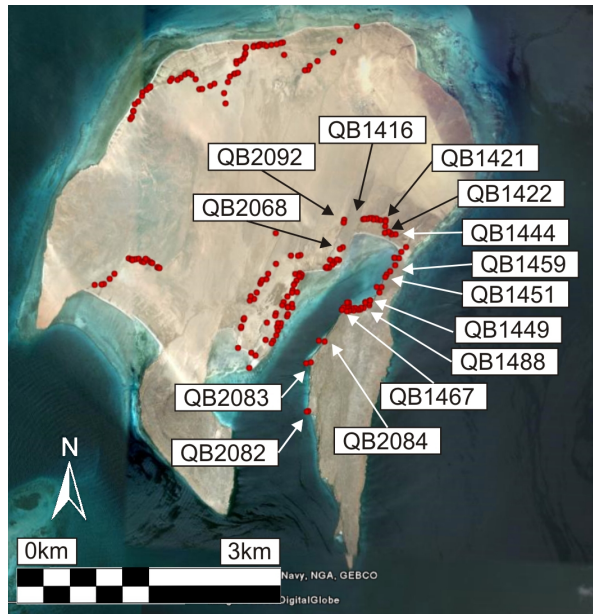


Figure 94: Location of dating samples from Qumah Island and Bay.

6.7 Southern Saqid Test Pits

Only two sites were test pitted in Southern Saqid due to time restraints. These two came from SS2150 and SS2500, the latter of these being from the excavated “hearth” (Figure 95 and 96). A full test pitting program of this area must be a priority for future work, since many of these sites will be at risk of destruction from future extraction activities.

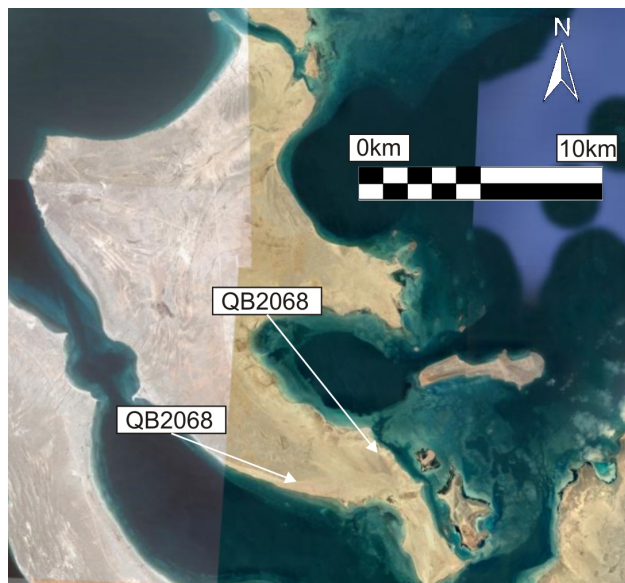


Figure 95: Southern Saqid test pit locations.



Figure 96: Hearth feature SS2500 (photo M. Williams).

6.8 Chapter Summary

The program of test pits has shown that (sampled) sites which belong to the same group share similar composition and structures. Composition will be controlled by the local availability of shellfish species; however prey choice and activities at the site are crucial, as demonstrated at sites in the Khur Maadi which tended to be dominated by either *S. fasciatus* or *C. reflexa*/*S. marisrubri*. Likewise the prevalence of *B. setigera* and *A. Avalana* on the surface of sites in Qumah Bay is strongly linked to local availability as well as prey choice.

The association of these sites both through internal examination and location on palaeoshorelines is suggestive of contemporaneity. The question which needs to be resolved is whether they are part of a longer history of continuous exploitation (both in individual areas and across the islands as a whole) resulting in the palimpsest of sites seen today, or whether they are indeed contemporaneous and the result of a single phase of intensive shellfish exploitation. The situation of sites along stretches of palaeoshoreline certainly suggests that they were contemporaneous, at least for related sections of palaeoshoreline. Dating of samples from these test pits in conjunction with dating the excavated sites should enable these hypotheses to be tested.

There is also the crucial question of how changes in the local coastlines impacted upon these sites and others in their groups. This theme will

6. Spatial Relationships of Shell Mound Building Activity

require geoarchaeological investigation of the palaeoshorelines, tied in with the dating program in order to put the sites into the context of coastal change.

Chapter 7

Coastal Change

7.1 Introduction

The preceding chapters have shown that many sites are located inland on palaeoshorelines, demonstrating the dynamic nature of the coastlines in this region of the world. To better understand the nature of coastal exploitation and the relationship of the sites to the coastlines on which they are located it is necessary to investigate the underlying processes effecting coastal change (eg Masselink and Hughes 2003; Holdoway and Fanning 2010). This will also offer the possibility to study human responses to coastal change and how behaviour was modified as a result.

The coastline on which JE0004 is located appears to have been relatively stable, however the change in formation processes of the site combined with the change in species composition might hint at subtler change. In contrast the Khur Maadi bay has clearly undergone extensive change and offers an opportunity to assess the impact of local environmental change on shell gathering activities. Efforts to understand these processes and responses will not be limited to the two excavated sites, with two further locations in Janaba West and on the Gandeel Peninsula also investigated.

Finding coastal features and sedimentary deposits which could inform on geomorphological processes is vital to interpreting coastal change. The extensive palaeocoastlines of the islands show that change has occurred. In order to quantify this change and its impact on shellfish gathering activity more detailed research is needed, particularly of sediments associated with these features. It is hoped that these can inform on the relationship between coastal change and shell mound building activities and lead to an assessment of social and economic responses to these changes. Geoarchaeological investigation will be a key methodology for understanding the social and economic responses of the shellfish gatherers to coastal change.

7.2 Methods

The methods used in this study will focus on assessing the palaeoshorelines' features and associated sediments. This was done by landscape survey, geoarchaeological trenches, and augering.

Projects such as the geoarchaeological investigation of the Muge Valley (Van der Schriek *et al.* 2007a; 2007b; 2008) have demonstrated the potential for this kind of research. In this case the authors were able to successfully reconstruct the evolution of the valley from flood plain to estuary and back to flood plain, and link human exploitation strategies to these changes.

The geoarchaeological techniques were tailored to each site as conditions dictated. The 2008 field season was used to located areas of sediment accumulation fronting palaeocoastline features. Geoarchaeological trenches were then excavated in order to determine the potential of the sediments and the extent to which they recorded changes in the local geomorphology. This was done through basic sediment description and assessment of grain size.

Sites were selected based on surface observations, by selecting low points in the topography where accumulated sediments existed. The deepest parts of the sediments were estimated by observing the lay of the land and calculating where slopes would meet beneath the sediment by basic geometry. The course of wadis could also be used to infer areas of deeper sediment. In areas where the topography was not suitable for the determination of the depth of sediment other indicators could be used such as the presence of vegetation.

The Farasan Islands are arid, with only occasional rainfall. Compounding this is the lack of developed soils, limiting plant growth to the occasional accumulations of sediment (such as in fissures). Where larger accumulations of sediment occur, such as those targeted by this geoarchaeological investigation, plant cover is slightly more abundant, but is still restricted to herbaceous species. With the exception of the mangroves, the only stands of

trees and shrubs occur in areas where water is more readily available. These are typically areas where sediment is deeper and can retain moisture better. Deeper topography is also likely to be closer to the water table allowing plants with longer roots to access these resources. Therefore stands of trees and shrubs were also investigated to determine whether they were suitable sites for geoarchaeological investigations.

The geoarchaeological trenches were excavated by hand using pick and shovel. A suitable section would then be cleaned using a trowel, and recorded. Bulk samples of 1kg were taken, either one per context or where the contexts exceeded 10cm one sample every 10cm. Dating samples were also recovered where suitable material existed.

Augering involved first selecting a suitable site where further information was required, and sediments were extensive enough. An Edelman auger (with “coarse sand”, “stony” and “riverside” drill bits) was used to core through the sediments in transects across the study area. The depth of the hole was assessed by measuring the length of the auger, and the sediments from each depth laid on the ground for assessment (Figure 97). This method does not provide as accurate results as opening a trench, since the auger drill bit resembles a cork screw. It works by disturbing the sediment as the cork screw is drilled down; the sediment is then retained in the drill bit, and can be extracted by hand when at the surface. The drawbacks are that the depths are approximate, and sandy sediments are disturbed so that any clear boundaries are lost, effectively time-averaging the deposit. However it is very useful to assess the general nature of the deposits and changes in sediment composition can be seen. The extent of the time averaging is roughly the length of the drill bit, so that each sample recovered will be mixed; but providing that material does not fall down the borehole then the sample will be a representation of that section.



Figure 97: Drilling a bore hole using an Edelman auger, samples laid out in foreground of photo (photo N. Al Shaikh).

Given that the sediment recovered from the boreholes was disturbed it was not sampled unless datable material (usually in the form of marine shell, since it is impractical to use these types of augers to recover sand for luminescence dating) was recovered. The sediment from the boreholes was recorded in the same manner as the trenches.

7.3 Results

During the survey a number of areas were identified which had thick layers of depositional material. The majority of these areas were embayments, where sediments had been deposited in more sheltered areas. However there are some exceptions to this, notably southern Saqid, which is covered by extensive sands 2-3m deep in a more exposed area of open coast. These are being exposed, and extracted for the building industry, along with the shell middens which are located on top of them.

Three key areas were identified and investigated as part of the field survey. All sites are located in bays, and all contain evidence of sedimentation and infilling. The three sites are Homer – a small inlet located to the North of the

Gandeel Peninsula; Janaba West; and Khur Maadi. Geoarchaeological trenches were excavated in all three in order to assess the depth and nature of the deposits, and the processes responsible for the in-filling of the bays.

In addition an auger transect was carried out across the Khur Maadi bay. It was hoped that this would complement the shell mound excavation (KM1057 in Chapter 5.4.1) and shell midden test pitting undertaken in this area. The geoarchaeological investigations would help to support this research by determining the geomorphology of the bay, and detecting changes in the make up of the bay over time which it was hoped could be linked to changes in shellfish gathering activity detected in the archaeological investigations of the bay.

The nature of the in-filled deposits in the bays was tested in the first season of fieldwork in 2008 by excavation; this led to an extension of investigations to include augering in 2009.

7.3.1 Gandeel Peninsula Geoarchaeological Trench – GP1268

The first area to be targeted with geoarchaeological investigations was the Gandeel Peninsula. The survey (Chapter 4) had shown there to be extensive palaeoshorelines along this stretch of coastline, and numerous shell midden sites. This was therefore one of the first areas of the islands visited in 2008; whilst surveying the peninsula an area suitable for geoarchaeological investigation presented itself at a location named on the map as 'Homer' (Figure 98). This site offered the possibility to assess changes in the geomorphology of the peninsula and its potential influence on local shell gathering activity.

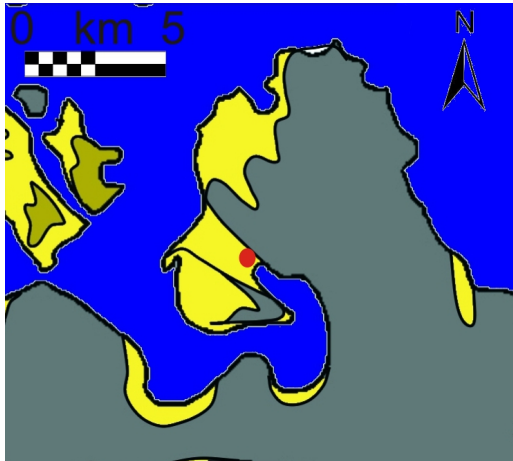


Figure 98: Location of Gandeel Peninsula geoarchaeological trench plotted on FCC image. Yellow is sand, dark yellow is coarse sand/thin sand veneer, olive is fossil coral bedrock.

The geoarchaeological trench at Homer was located in the bottom of a shallow valley, where sediment had accumulated in the base. The sediments were enclosed on three sides by valley side, with a narrow opening onto an open plain to the west. Adjacent to the narrow opening is a low rise which appears to show evidence of uplift. To the east a small wadi fed the valley; the valley sides were all composed of fossil coral, with no sediments present except in the valley base. Excavation in the centre of the valley yielded a 78cm profile down to bedrock (Figure 99). The first four centimetres at the top of the profile were composed of a loose crumbly topsoil. Below this a further 26cm was brown, firm fine silt, with roots present. The origin of the sediments is uncertain, the presence of roots could indicate either terrestrial or mangrove origins. However the absence of any shells strongly suggests a terrestrial origin, since shells associated with mangroves would have been found. Therefore the top 30cm of the profile are likely to have a terrestrial origin; the sediment is likely to have been accumulated in the valley via the wadi course.

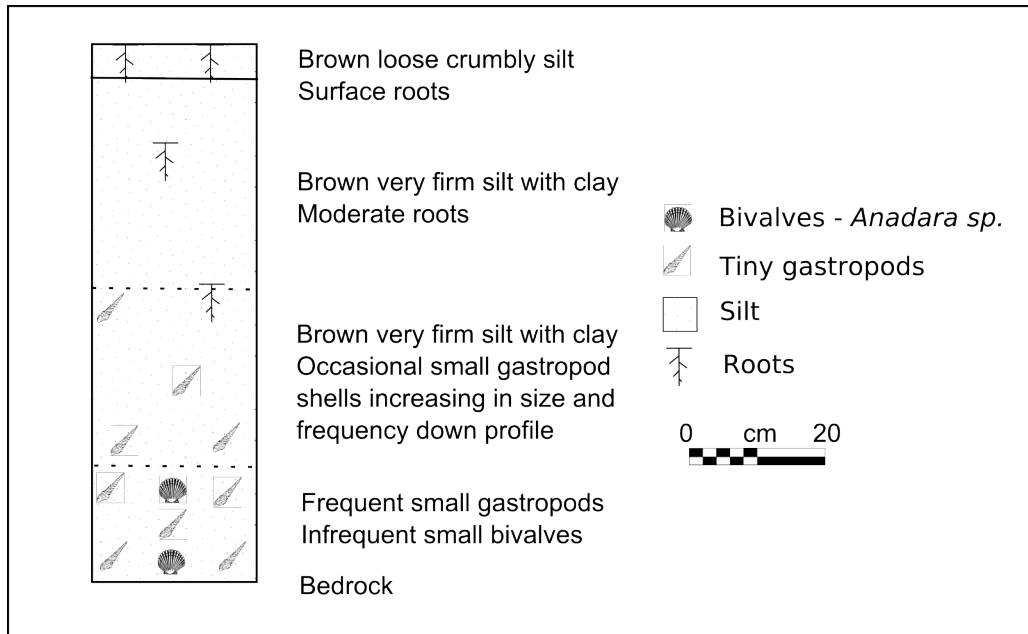


Figure 99: Profile of geoarchaeological trench from Homer, Gandeel Peninsula.

Below 30cm shells start to appear in the sequence, and increase with size and frequency downwards. Between 30-55cm the shells are of small gastropods c.0.5-2cm long, common in shallow water. Below 55cm small bivalves also start to appear, predominantly *Anadara sp.* and small limestone pebbles are present. The trend for increase in size and frequency continues to the base of the profile at 78cm which is bedrock.

This sequence shows a slow silting up of the bay, which resulted in the gradual contraction of shellfish habitats. No edible shellfish specimens were recovered from the trench; however this site demonstrates the change from marine to terrestrial in the area, and the potential for the existence of shellfish beds in slightly deeper water. This is demonstrated by the presence of shell midden sites to the immediate north and south of this valley.

Sedimentation does not appear to be the only process effecting the transition of the bay from a marine to terrestrial environment. The surface of the valley floor is currently 4m above sea level. This suggests that the land has been uplifted by at least 3.70m when sedimentation is taken into account. The presence of potential uplift features in the bay also supports this conclusion. If this uplift and sedimentation was contemporaneous with shell mound building

activity it would have had a considerable impact, reducing the productivity of the shell beds.

7.3.2 Janaba Bay West Geoarchaeological Trench – JW1650

The presence of a pocket of dense vegetation in Janaba Bay West suggested that an accumulation of sediment may exist in the bay (Figure 100).

Investigation of this found several large palms and an under-story of shrubs within a 20 meter area. This was situated in a shallow but prominent wadi running across the palaeobay. The watercourse had cut through the sediments exposing a c.40cm section. There are also a number of shell scatters in this area located between the palaeo and modern shorelines, which tracked the retreating coast. This is highly relevant as it records a response in exploitation strategies to coastal change.



Figure 100: Location of Janaba West geoarchaeological trench plotted on FCC image. Yellow is sand, dark yellow is coarse sand/thin sand veneer, and olive is fossil coral bedrock.

Excavation into the base of the watercourse extended the exposed section to 92cm (Figure 101). The profile was predominantly composed of brown silt, with some small blocks of coral bedrock incorporated into the silt at the base.

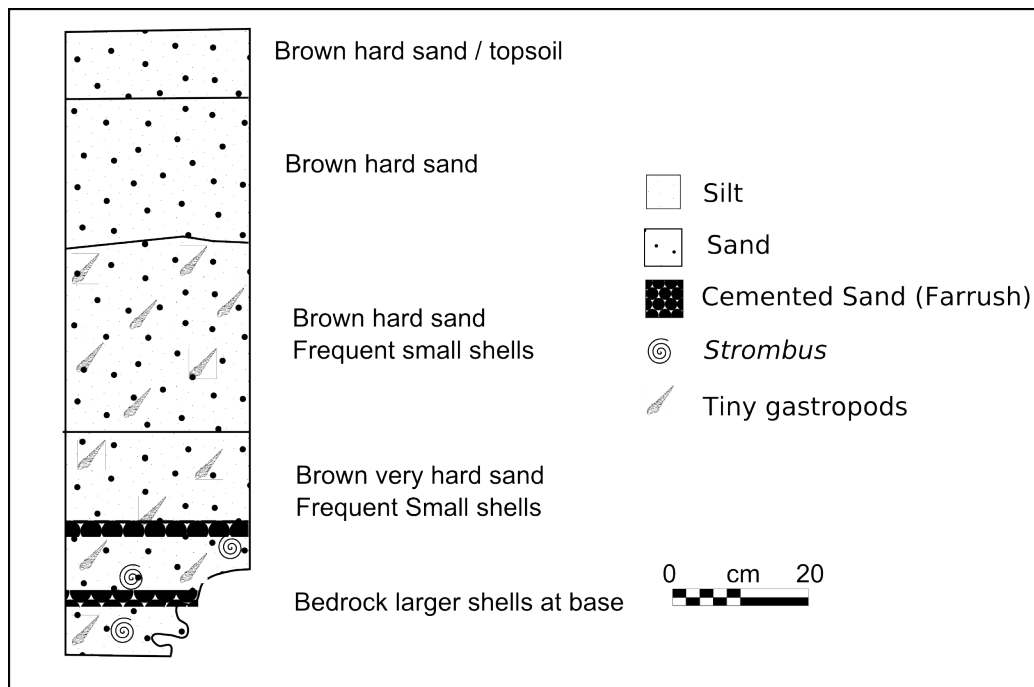


Figure 101: Profile of geoarchaeological trench JW1650.

The uppermost 10cm of the profile are composed of crumbly silty sand and topsoil; below this is a further c.20cm of clean sandy silt. At 30cm small gastropod shells start to appear, these increase in size (from <0.5cm) and number down the profile; the final c.5cm of the section is composed almost entirely of these small gastropod shells (now up to 2cm in size). Two *S. fasciatus* shells were also found at the base of the profile. Two layers of partially concreted shells at 72cm and 82cm indicate that farrush formation was initiated, but did not continue.

This exposure provides evidence for shell beds at the lowest levels, when *S. fasciatus* of edible size would have been available. However, the predominance of smaller gastropods in silt suggests a lower energy environment in this part of the section. Combined with the absence of juvenile *S. fasciatus* it is possible that the adult specimens found at the base of the deposit either strayed or migrated in from *S. fasciatus* beds close by or were brought in by some other agency such as water currents or predators.

There could be a case for the sediments being reworked and redeposited by the wadi in this location; however the presence of farrush (eg Schmalz 1971; Hanor 1978; Scoffin and Stoddart 1983; Alsharhan and Kendall 2003; Kelletat

2006), combined with the lack of damage to the shells suggests that the deposits are in situ and were not reworked.

This geoarchaeological trench shows the transition from shell bed to terrestrial deposits. Subsequent analysis of higher resolution satellite images has also detected the presence of micro-raised beaches (Figure 102), raising the possibility of quantifying rates of change along this section of coastline. The impact of this coastal change on shellfish gathering activities would have been twofold, with the sea retreating and local shellfish habitats changing (eg Turney and Brown 2007).

A useful case study for this type of scenario comes from the area around the geoarchaeological trench. A number of scatters lie between the palaeoshoreline inland and the modern day shoreline, roughly following the course of a wadi. Micro-palaeocoastline features are visible in this area, as a series of raised beaches (Figure 102). The distance between these features ranges from c.2-20m over a distance of c.600m between the palaeocoastline and modern coast. This would suggest that periods of stability were present but short-lived, and movements were regular but limited in size. This is mirrored in the nature of the sites in this area, which are shell mounds on the main inland palaeoshoreline, and small scatters between this and the modern day shoreline. A key question is whether the sites are restricted in size due to reduced productivity in the shell beds or the rapidly moving shoreline not allowing time for greater accumulation at the water's edge (eg Turney and Brown 2007). Again these sites have not been dated, and this must be a priority for future work. Dating these sites would perhaps offer an insight into when the coastline started to change, the rate of change, and how long fisher-gatherers persisted with this activity in this area. However the challenges encountered in dating could mean that the resolution is not sufficient to answer all of these questions. The composition of these sites adds a further complication; they are predominantly composed of *C. ramosus* and *P. trapezium*, but are located on a sandy raised beach. The absence of species from sandy substrates is odd considering this; however the geoarchaeological investigations suggest that this supported only immature or stunted *S.*

fasciatus in low densities. *C. ramosus* and *P. trapezium* favour rocky substrates, meaning foraging must have occurred further offshore on rocky substrates.

A similar sequence was found in JW1650 geoarchaeological trench, where shallow subtidal conditions, with evidence for a *S. fasciatus* shell bed, was found to give way to shallower subtidal sediments dominated by tiny gastropods forming a berm or chenier ridge. Indeed this berm of small shells was also detected further up the shoreline. Test pits into site JW1659 showed that this site was in fact deposited on top of the berm of tiny shells, which perhaps marked the high water point when then mounds were deposited. Although this might be seen to complicate the interpretation of the deposition of these shell mounds – are they natural or anthropogenic? It is fairly easy to distinguish between the two based on stratification and the size of shell (eg Bailey 1993). The small inedible shells of the berm are overlain by layers of larger edible sized shells only. In other regions of the globe it has been necessary to develop other methods to make this distinction (eg Rosendahl *et al.* 2007).

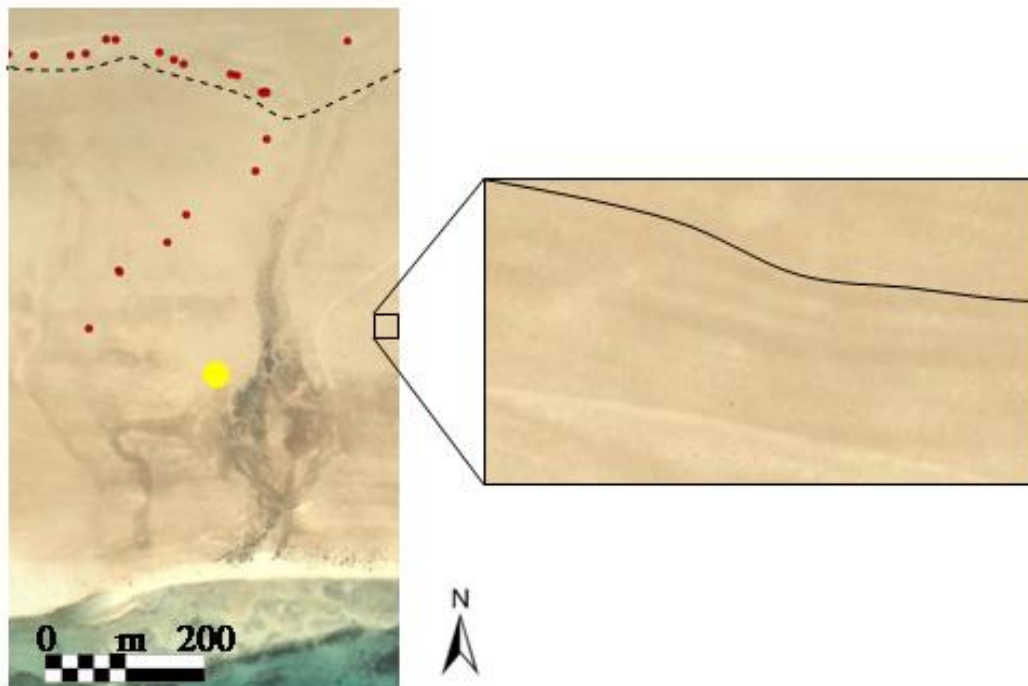


Figure 102: JW shell scatters on multiple raised beaches. Left – red dots indicate sites, dotted line marks palaeoshoreline with shell mounds. South of

this red dots are shell scatters, yellow dot is geoarchaeological trench; runoff channel is clearly visible as darker area. Right – close up of multiple raised beaches, black line highlights one of these features.

These sites show that sea level had a profound effect on fisher-gathering, and in this location was probably responsible for the cessation of shell mound building activities. However this was not instantaneous and shellfish gathering did continue on an apparently more limited scale as the sea withdrew. Only dating of these deposits will inform on the timing of these events.

7.3.3 Khur Maadi Geoarchaeological Trench and Auger Transects

The Khur Maadi bay is one of the key research areas on the islands with one site having been excavated and a program of test pitting undertaken for a number of other sites. It is a wide palaeobay extending inland where it meets the Janaba West Bay (Figure 103). This meeting of the bays would have split Farasan Island into two halves by a shallow subtidal/intertidal channel. Along the former shorelines of the bay are numerous shell midden sites on a range of scales from small scatters c.2m² to mounds up to 3m high.



Figure 103: Location of Khur Maadi geoarchaeological trench.

Investigating deposits in this area would allow shell mound building activity, particularly of the excavated site KM057, to be put into context with geomorphological change in the bay. A geoarchaeological trench was

excavated in the centre of the bay; this was followed by auger transects across the bay to attempt to better understand the changing geomorphology.

During the survey the Khur Maadi bay was observed to have sediments consistent with having been in-filled. The presence of a stand of vegetation in the centre of the bay, similar to that found at the Janaba West geoarchaeological trench was interpreted as deeper sediments with higher water availability. These proved to be on top of a sediment sequence and a geoarchaeological trench was excavated into this, reaching a depth of 138cm. This was the most complex profile of the three geoarchaeological trenches excavated, being composed of silts up to coarse sands in layers and lenses (Figure 104).

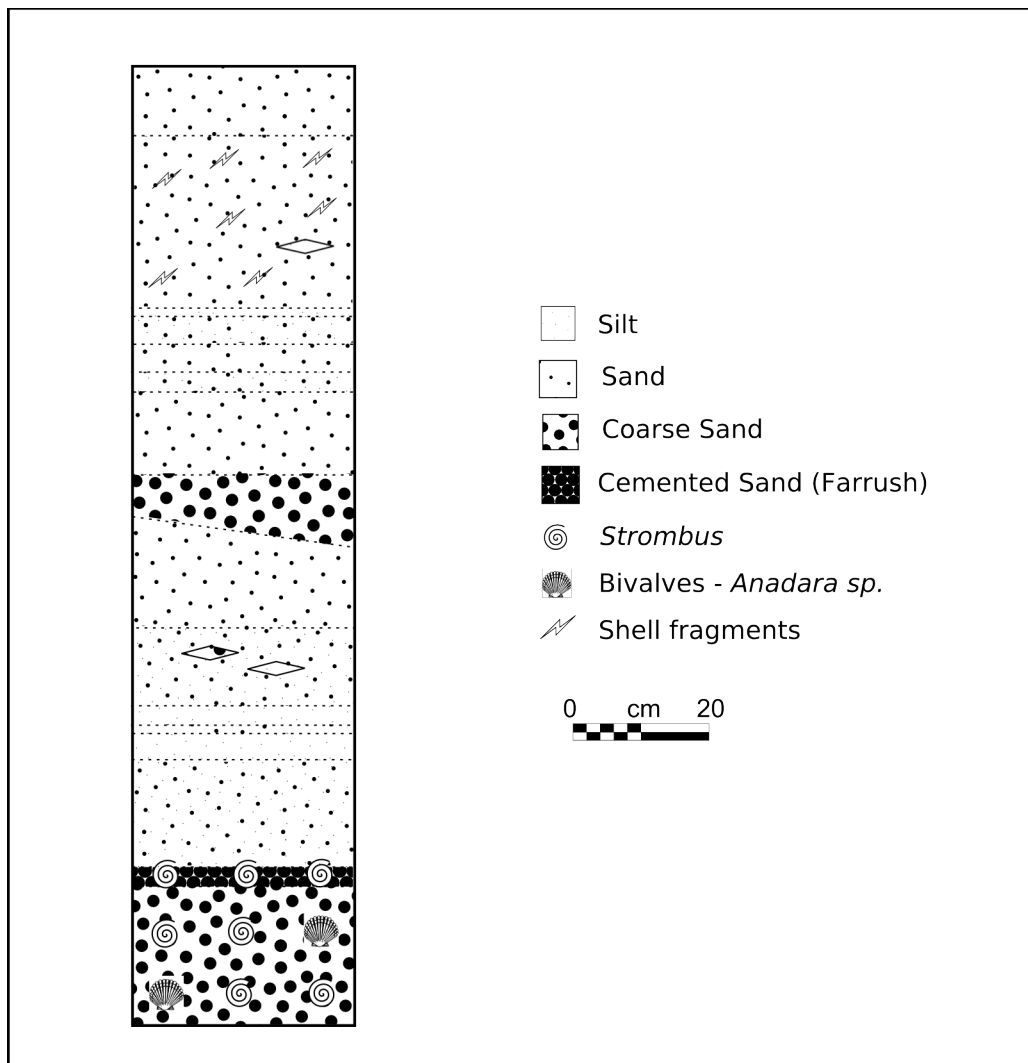


Figure 104: Profile of Khur Maadi geoarchaeological trench.

The base of the site is dominated by coarse sands with some evidence of farrush formation. Within these sands are numerous shells, predominantly *S. fasciatus* and *Anadara sp.* which represent an in situ death assemblage, a biogenic taphofacies, of juveniles through to adults; bivalves were paired in life positions. These would have been highly productive shell beds.

This is overlain by less coarse sand, which in turn is overlain by a distinctive layer of darker grey silt. In turn this is overlain by sandy silt, then a layer of silt with rare sand, then another layer of sandy silt (with a lens of coarse sand and a lens of silt). This is followed by a thicker layer of sand, then coarse sand. Over the coarse sand is a succession of progressively finer sediments (a fining up sequence) to silt. This is overlain by sand (with a lens of silt) and finally overlain by coarser sand.

This sequence represents the transition of the bay from a productive shell bed through to a terrestrial environment. The in situ shells in the basal sediments suggest that these species (in particular *S. fasciatus* which is a key constituent of many shell mounds) preferred slightly higher energy environments. Modern observations show that *S. fasciatus* grow in shallow subtidal waters, where they graze on sea grass. Sea grass grows on a sheltered sandy substrate where currents are strong enough to maintain the coarse sandy substrate without the accumulation of silt.

The decrease in sediment grain size above the basal sediments indicates that geomorphological conditions were changing, and that the centre of the bay was becoming a lower energy environment. This is possibly a result of the bay becoming shallower; a thin layer of farrush on the upper layer of the coarse basal sands suggests that this area was approaching the intertidal zone, and becoming exposed. However this abruptly shifts to finer sands and silts, interrupting the formation of the farrush. This sequence continues, with fluctuations between finer sands and silts, representing shifts within a lower energy environment. It is likely that this area became influenced by the formation of a spit to the west, which deflected the stronger water currents resulting in lower energy and silt accumulation. The variations in grain size are

likely to represent micro-scale shifts in the local drainage, with small channels activating and de-activating through time. As the bay in-filled and uplifted runoff from inland would have begun to influence this area, since it is the lowest point of the bay. Runoff events may have played a role in the deposition of the sands in between the layers of silt; however it is not until higher up in the profile that this becomes obvious. Different sized events could have deposited anything from fine silts up to the more coarse material depending on their magnitude.

Between 60-70cm (from the top of the profile on Figure 104) there is a clear erosion event (demonstrated by the slanting layer) followed by the deposition of coarser sand. Although it is still possible that this event was caused by coastal processes, such as a shift or breach in the spit caused by a storm, the more likely scenario is that this resulted from a runoff event. The sediments between 10-36cm (from the top of the profile) are most likely the result of a large runoff event, and have large quantities of shell fragments incorporated into the sand. This material has most likely been eroded from further inland, in the palaeobay, before deposition at this site. However it may also be representative of a shallow marine environment where material has been reworked; uncertainty over the role of local tectonics adds to the difficulty in interpretation. Uplift could have changed the energy levels and sediment budgets of the bay, initiating the accumulation of sediment and perhaps effecting patterns of accumulation/erosion through the sequence.

Satellite images suggest that runoff still plays an important role in the geomorphology of the bay. Longshore drift is a predominant force, moving sediment along the coast from west to east. However a small open channel has been maintained from the bay to the sea, past the spit. This suggests that the channel is periodically washed clear by runoff events, which are large enough and regular enough to prevent sediment build up. This would support the former hypothesis of a runoff event depositing reworked material in this area.

The geoarchaeological trench had revealed a promising sequence leading to the decision to undertake a more intensive study of the palaeobay and surrounding environment. The objective of this investigation was to assess the extent of deposits within the Khur Maadi palaeobay, and tentatively reconstruct the geomorphological evolution of the bay. This would be carried out using basic hand augering equipment.

Two transects were cored across the palaeobay (Figure 105); one on an east-west axis crossing one side of the bay to the other through the geoarchaeological trench (sites – BH13; BH03 the geoarchaeological trench; BH08; BH07); the other from the northeast to southwest, along the eastern side of the bay (sites – BH06; BH05; BH04; BH08; BH09; BH10). Two further cores were taken on the west side of the bay (BH01; BH02), and a further cluster was drilled in the vicinity of the shell mounds on the west side of the bay (BH11; BH12; BH13; BH14).

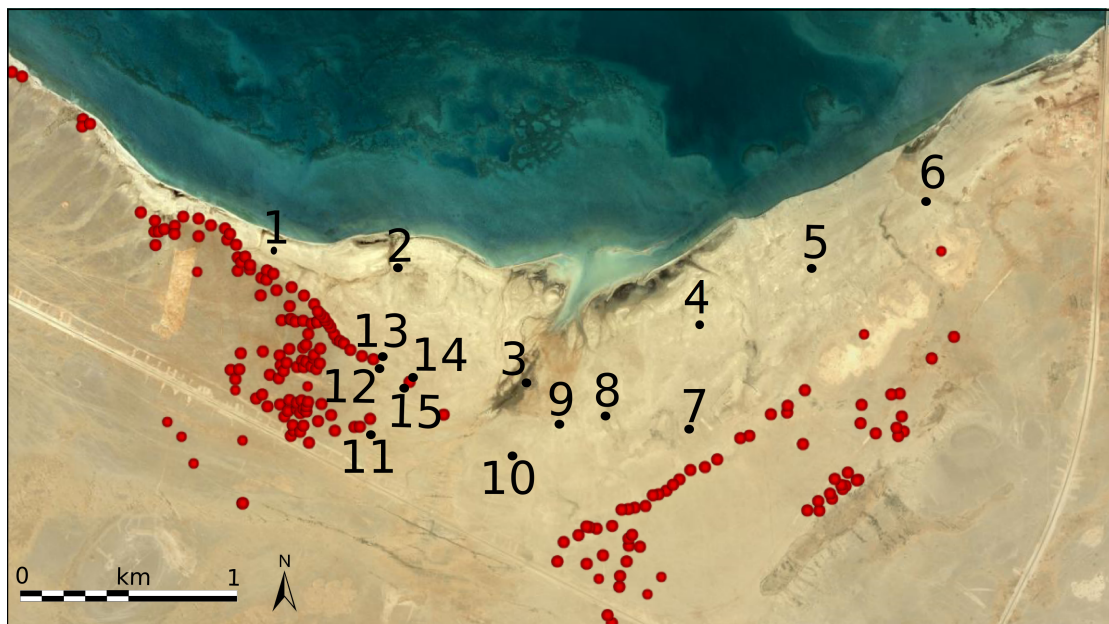
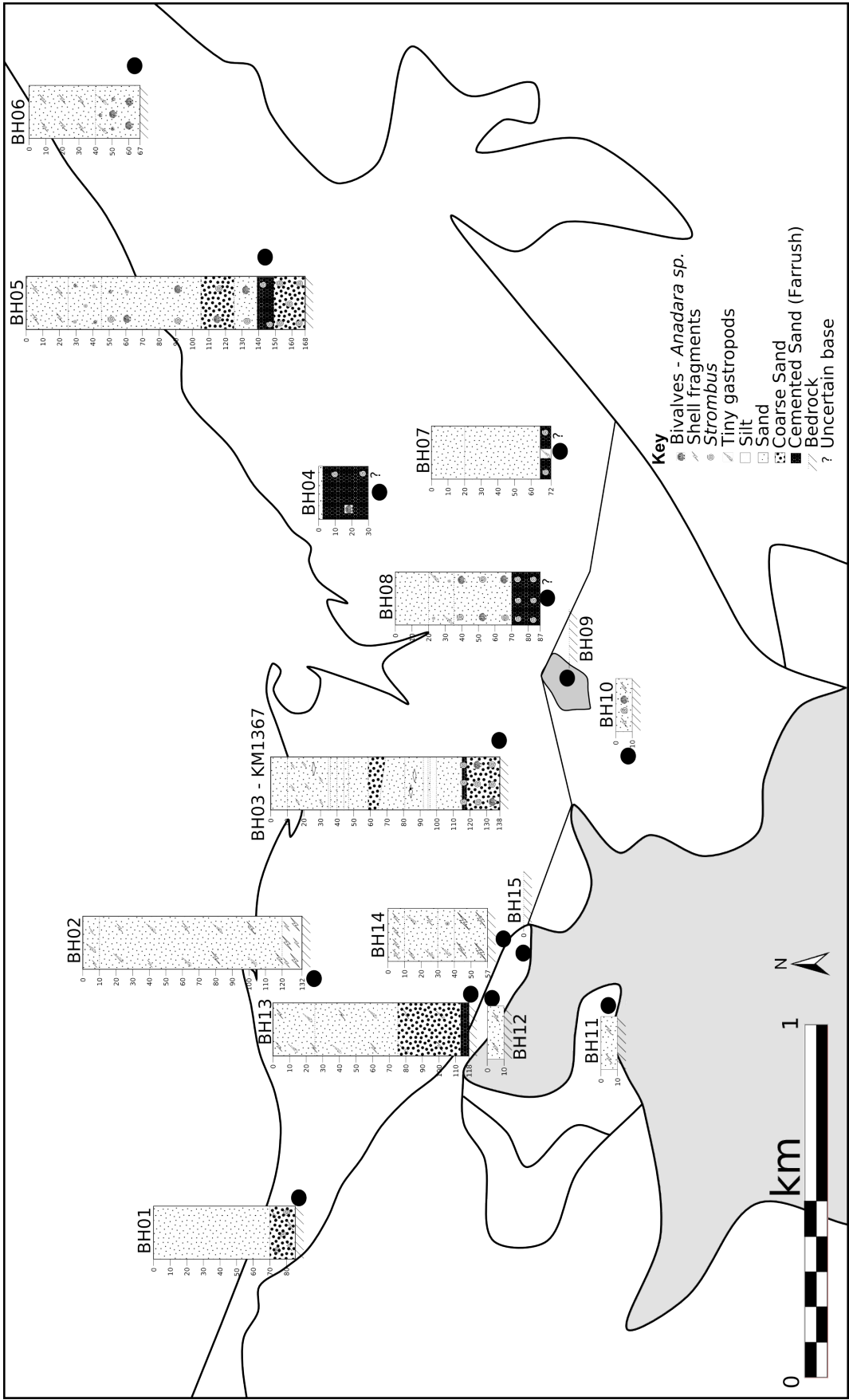


Figure 105: Location of auger boreholes across Khur Maadi. Red dots indicate known shell midden locations. Numbers indicate auger borehole sites, with the exception of number 3 which is geoarchaeological trench KM1367 (revisited during augering).

The bore holes showed a high degree of variability in depth, with three being hindered by the presence of farrush (Figure 106). This creates a concreted layer, through which it is often impossible to drive a hand powered auger.

Therefore these boreholes had to be abandoned, and the depth and composition of the sediments in these locations are unknown. Farrush was encountered in other boreholes (such as BH05), however this proved to be softer and it was possible to drill through and assess the sediments below. The borehole data suggest that the bay is divided into two distinct zones, the inner and the outer bay.



The outer bay is dominated by sandy deposits, exceeding a meter in depth in most areas. There is some variation in the grain size of the sand, with large grain sizes indicating higher energy environments. Shell fragments within many of the deposits support this hypothesis. The presence of farrush within many of the cores (BH03, BH04, BH05, BH07, BH08 and BH13) is evidence of stable intertidal zones, where evaporation has resulted in the cementing together of the sand. The presence of this phenomenon at the base of many of the cores suggests that the bay has undergone extensive change, since many are overlain by deposits containing evidence of further shallow subtidal and intertidal environments. This evidence includes the presence of shellfish, broken shell, and in the centre of the bay in the geoaechaeological trench, organic silts which would have been shallow mud flats.

The inner bay is markedly different from the outer, being much shallower. The two areas are separated by an abrupt change in depth, most likely the result of a small cliff, the continuation of which can be seen on either side of the bay, dipping down beneath the sediments. This is evidenced by the difference in the thickness of deposits between BH12 and BH13; BH14 and BH15; BH08 and BH09; and the proximity of BH03 to BH09 and BH15. An extensive area of the inner bay, to the south of BH09, BH12 and BH15, is characterised by bedrock, with little or no overburden. Where overburden was present (BH10 and BH11) it proved to be little more than 10cm thick. This area is now over 4m ASL in places (further inland one area reaches 10m ASL); this is strong evidence that the bay has undergone extensive tectonic warping and been uplifted from below sea level to well above it. The transition between these two areas is now obscured by sediment which gives the appearance that the palaeobay slopes gently down towards the sea with no major change in gradient.

The gentle slope of the bay has tectonic origins, evidenced by the presence of large fissures (cracks) across the fossil coral of the inner bay and DTM. These run east-west across the bay or perpendicular to the slope towards the sea (Figure 107). Without the presence of the shell

mounds located around the edge of the inner bay, it would have been impossible to reconstruct the palaeobay. The DTM reflects the contours of the uplift, making it hard to reconstruct the palaeoshoreline using this data. Likewise any sediments which once covered the interior of the bay have long since been eroded, probably coinciding with the uplift and increased water runoff from inland. The eroded sediment would have combined with the longshore drift (seen on the satellite image in Figure 80 as sand bars and spits stretching west to east in the centre of the image) to quickly fill the outer bay, burying the cliff. The detection of this feature would not have been possible without the program of auger boreholes.



Figure 107: Highlighted features of the Khur Maadi Bay: black lines are cliffs with associated linear distributions of shell middens marked by red dots; blue circles indicate areas of distributed shell middens; circled red are fissures; yellow circle indicates former inlet.

This new information on the configuration of the bay raises a number of questions about the formation processes and evolution of the bay. Before the presence of the buried cliff was identified, the interpretation of the bay seemed straightforward. At either side of the bay the small cliffs reduced in size until they ended at the mouth of the bay. The bay then opened up getting progressively shallower inland. At some point after the formation

of the shell mounds the inner bay was uplifted with the outer bay in-filling with sediment.

However, this scenario is complicated by the continuation of the cliff-line across the bay. For the cliff to have formed the coastline must have been stable for a period of time. Formation was perhaps accentuated by episodes of earlier uplift which would have stretched the overlying rocks, making them more prone to erosion, and therefore cliff formation. At this time the cliff would have been at sea level, and the inner bay would have been dry (Figure 108.1). It is unclear whether shell mound building was initiated during this phase; present indications are that shell mound accumulation post dates this phase, since the cliff would have started to form when sea levels stabilised c.6000BP, and the earliest dates for shell mound building are c.5500BP (Zarins and Al-Badr 1986).

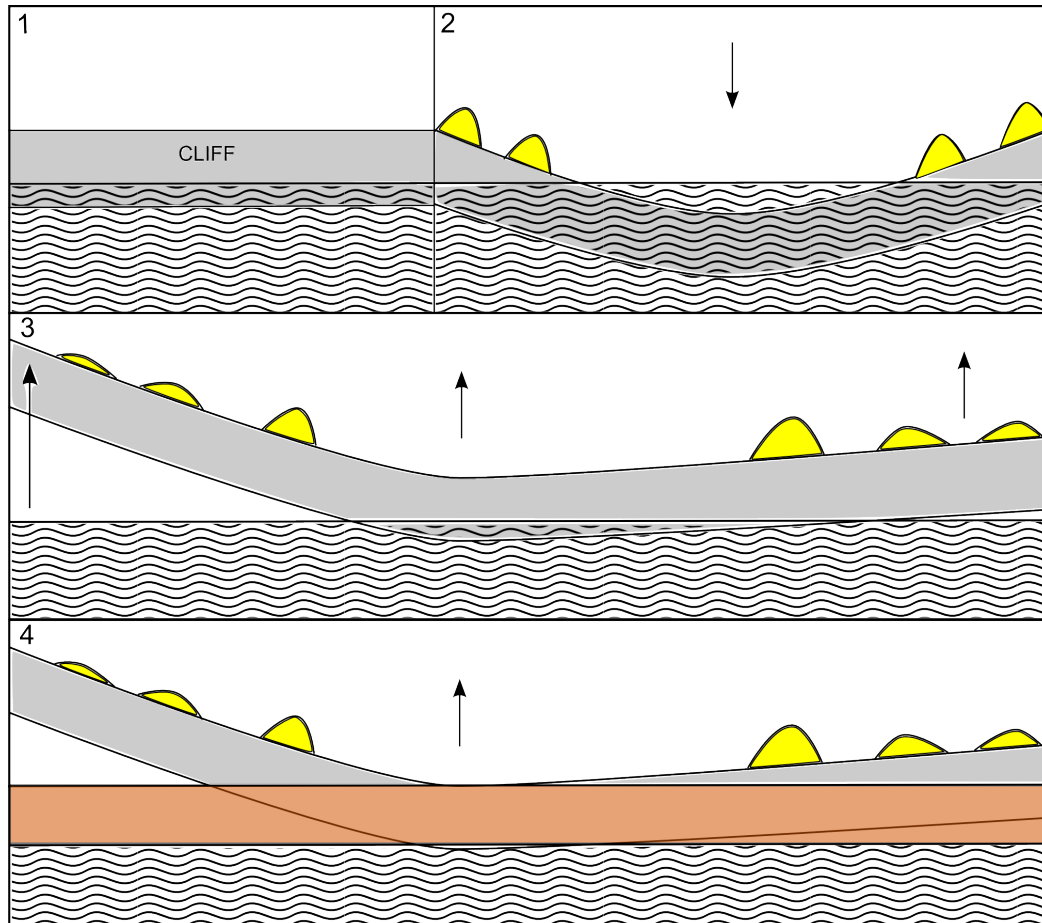


Figure 108: South facing schematic of Khur Maadi cliff in relation to sea level and effects of warping. 1: Formation of cliffs during episode of stability c.6000BP. 2: Localised warping depresses cliff allowing water to spill over forming a bay inland; shell middens accumulate both on exposed cliff and around bay. 3: Uplift raises the cliff, the bay is lifted above sea level drying out; uplift is greater to east. 4: Bay in-fills; sediments of marine origin in the bay are uplifted above current sea level.

Following the formation of the cliff, a large area subsided (Figure 108.2), bringing a section of the cliff below sea level, and flooding inland forming the shallow inner bay. It is during this period that the shell mounds accumulated, taking advantage of a small window of ecological opportunity.

It is uncertain how long the inner bay was inundated. Certainly the position of the shell mounds, with an irregular distribution, suggests that the shores of the bay were changing through time. In one area, to the west of BH11, it has been possible to reconstruct three separate palaeoshorelines from the location of the shell mounds. During their

accumulation the shore would have remained stationary long enough for the deposits to accumulate. However no palaeoshoreline features have been found in the inner bay, suggesting that sea level in this area was never stationary long enough for these features (such as cliffs) to form. If they had formed they would have been more ephemeral such as raised beaches which have since been weathered away.

A period of uplift pushed up the inner bay above sea level and raised the submerged section of cliff back up to sea level at (or close to) its present position (Figure 108.3). It is uncertain whether shell mound accumulation had already ceased at this time, or whether this was the cause of their cessation. Certainly evidence from BH03-KM1367, BH05, BH07 and BH08 suggest that productive *S. fasciatus* beds existed in the outer bay at some point during this period. However as the outer bay became infilled these ceased to be productive (Figure 108.4).

From the results presented above it is possible to infer a number of different landscape features and environmental settings which once existed in the Khur Maadi; these are presented in Figure 109.

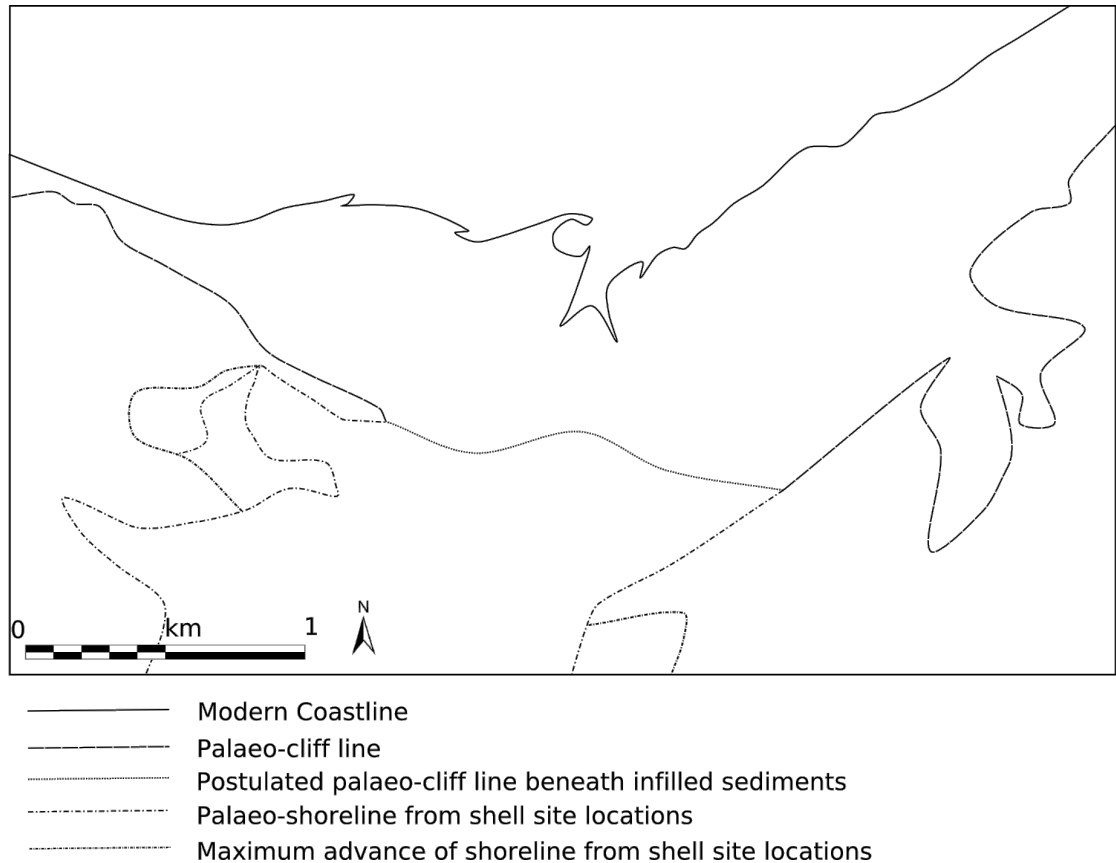


Figure 109: Khur Maadi coastal features both observed and inferred from geoarchaeological investigation.

The Khur Maadi geoarchaeological investigations are the most intensive carried out on the islands, and have allowed a tentative reconstruction of the evolution of the bay. It is clear that tectonics have played a key role in the formation of the bay, and its subsequent in-filling. This would have had a profound effect on shell bed productivity and shellfish gathering. The distributed pattern of shell middens within the interior of the bay suggest that conditions were shifting regularly, perhaps even seasonally. However it is unlikely that small scale changes can be detected and correlated in either midden or bay sediments unless Micromorphology is undertaken and combined with high resolution dating. A much more attainable outcome would be to link larger changes in the bay such as the decline in the shell beds to the chronology of the adjacent shell midden sites.

7.4 Chapter Summary

These results have detailed some of the extensive change which has affected the coastlines of the islands. It has shown that one of the principle underlying processes for this change is uplift, rather than in-filling alone. The impact upon shellfish gathering activities is likely to have been severe as the productivity of the shell beds changed in response to changes in the local geomorphology. However in Janaba West coastal exploitation was seen to continue with a change in target species, probably responding to changes in species availability. In order to quantify the impacts and responses and to put these into context both shell middens and geoarchaeological sediments need to be dated.

The geoarchaeological program has shown also the value wider multidisciplinary investigations. What initially appeared to be a straightforward process of in-filling or uplift has turned into a more complicated sequence of events. Although further investigations will be needed to better assess the timings of these events, this study has highlighted the complexity of investigating sites in this region.

For the potential of these investigations to be realised the sediment chronologies need to be correlated to the shell midden deposits. In order to achieve this, dating techniques must be applied. This will allow any social and economic responses to coastal change to be assessed.

Chapter 8

Temporal Relationships

8.1 Introduction

Dating the deposits (both shell midden and geoarchaeological) was one of the most important methods of this project as it allows the sampled sites and sediments to be put into context both with each other and more broadly to regional patterns. At the inter-site level it allowed an assessment of the relationship between sites and different groups of sites. It also allowed these sites to be put into context with coastal change and an assessment of social and economic responses to these changes to be made. At the intra-site level it allowed the formation processes to be quantified and rates of deposition to be assessed. The dating program ties all of the research together and allows the research questions to be addressed, linking all of the previous results chapters.

The archaeological remains of the Farasan Islands have yet to be dated in a systematic manner, with only three radiocarbon dates coming from unprovenanced deposits. Although these have given a good indication of shell mound building activity which fits in with the regional pattern of activity, further dating is needed develop the our understanding of the sites further.

Dating of the deposits followed a logical order; first top and basal rangefinder dates for the two excavated sites were processed, followed by the base of the Khur Maadi geoarchaeological trench. This allowed an assessment of which excavated site to focus on for a high resolution dating program, in order to address the question of the rate at which the formation processes of the shell mounds occurred. The dating of the KM geoarchaeological trench allowed shell mound building activities at KM1057 to be put into context with changes in the local geomorphology.

These dates were achieved using radiocarbon dating which also allowed for the second step of the dating project: a trial of the amino acid racemization (AAR) technique in this region. Testing the AAR dates against the rangefinder dates (using paired samples from the same

contexts) helped determine which method had the highest resolution and was therefore most suitable for a high resolution test. It was hoped that the higher temperature and faster rate of racemization would result in more accurate AAR dates. This would allow for a higher resolution investigation for the third step of the dating program, to test the rate at which the formation processes of the shell mounds occurred. However testing proved both AAR and radiocarbon to have comparable errors.

The third step was to utilise one of the dating techniques to undertake a high resolution dating program of the stratigraphy of the shell mounds, should the rangefinder dates demonstrate a long enough history of accumulation. The rangefinder dates overlapped for KM1057 (two dates derived from marine shell), but suggested the potential for longer accumulation at JE0004 (one date derived from marine shell, the other from charcoal). Given the uncertainty with AAR it was decided to use radiocarbon dating to undertake the high resolution dating of the accumulation of JE0004. Bayesian statistics were used to construct a deposition model for the site in order to quantify the formation processes. During this process it became apparent that the nearest local marine reservoir correction value in the Red Sea was incompatible with deposition model for the site. A quick test was undertaken to assess the value which resulted in a much better fit. Using this new figure suggested that the initial rangefinder dates for JE0004 were almost identical.

The fourth stage of the dating program was to date a wider range of sites from samples taken during the test pitting program to determine the temporal extent of shellfish exploitation. This was primarily done using the AAR method, as it offered the potential for further testing of the method. This stage of the dating program tested the spatial relationship of shell mound building and determined whether shell mound building occurred during a single intensive phase or was the result of a longer accumulation of sites over time.

The fifth and final stage involved undertaking AAR kinetics and heating tests to further validate the method and investigate archaeological processing of the shell. The kinetics test helped to further refine the resolution of the AAR method by determining the natural trajectory for racemization at a set temperature. The heating test was used to ascertain whether archaeological heating of shell is detectable during AAR processing; this helped shed further light on social and economic aspects of shellfish processing.

8.2 Methods

The two key methods used for dating archaeological samples and sediments are radiocarbon dating and AAR geochronology. The introduction has laid out the structure of the dating program and how this relates to the research questions. This section is broken down into two components dealing with radiocarbon dating and AAR dating, and how the samples were selected. The final section will discuss how Bayesian statistics was used to create the deposition models of JE0004.

The choice of dating method needed to have both resolution and flexibility in order to have applicability across the research area. A number of papers have attempted to assess some of the more popular dating methods against one another and these proved a useful guide (eg Magnani *et al.* 2007; Bateman *et al.* 2008; Magee *et al.* 2009). The most plausible scenario involved using more than one method to complement each other in order to obtain as much information as possible.

8.2.1 Radiocarbon

Radiocarbon dating provides one of the most versatile methods of dating for sites and samples under thirty thousand years old (eg Ramsey *et al.* 2006, Bateman *et al.* 2008). It is not without difficulties or complications but can be applied to a wide range of materials and when applied

sensibly can be very informative and form an important part of a project (eg Turney *et al.* 2006).

Radiocarbon dating is a very common method used in archaeological investigation, due both to its versatility (it can be used on any material containing archaeological carbon) and the extent to which it has become established as a primary method of absolute dating. Due to the nature of the shell bearing sites on the Farasan Islands radiocarbon dating again proves a useful tool for dating the sites. Very little typological material (eg lithics) is present on the islands from the period of shell mound building (which are aceramic). The few stone tools which are present are often from unstratified contexts, being found on the surface of the mounds, or on the adjacent coral terraces. Even if more lithics had been found in stratified contexts a problem would still have remained since very little work has been carried out on lithic development, meaning that any chronology would be inferred from adjacent regions and cover broad periods of time. The stratified deposits are dominated by shell, with a small contribution from sediment (sand/silt/ash) and a tiny fraction of charcoal and other organic remains such as fish bones, crab exoskeletons, and a very limited number of mammal bones. This reduces the dating possibilities even further.

Radiocarbon dating suffers from a number of drawbacks, not least the prohibitive cost of processing samples. In addition the calibration curve has a number of plateaus which can result in dates having a larger error than might be anticipated. For the period during which shell mound building activity is most likely to have occurred (6000-4000 years BP) there is a significant plateau. This could give rise to three intercept points on the radiocarbon calibration curve, which simply put means that there could be up to three different possible dates for any given radiocarbon dating sample which falls into this period. The figure below shows the extended calibration curve, and an example of a single radiocarbon date with associated calibration curve with numerous intercepts (Figure 110).

8. Temporal Relationships

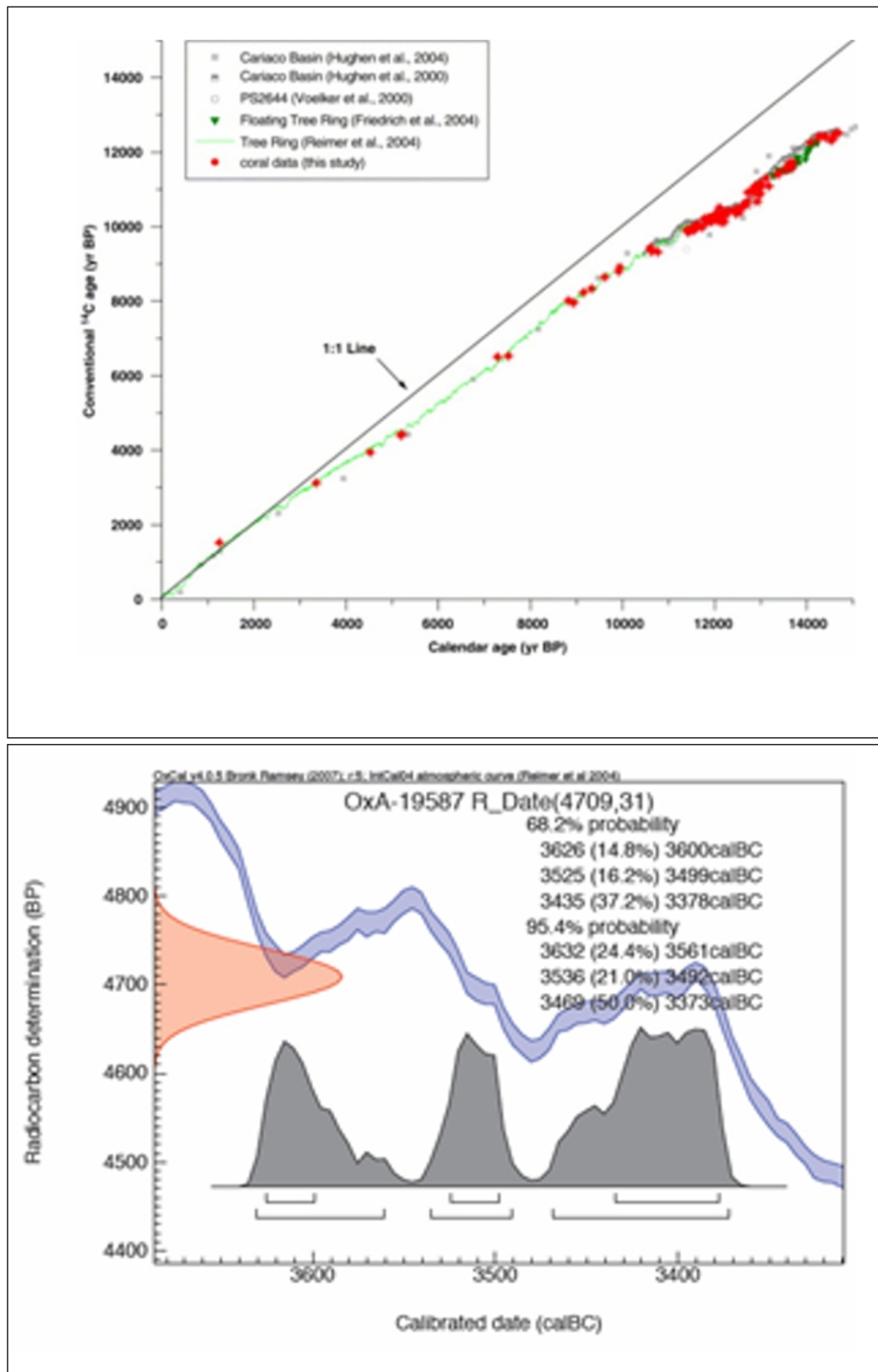


Figure 110: (Upper) radiocarbon calibration curve spanning 0-50'000 years BP based on paired $^{230}\text{Th}/^{234}\text{U}/^{238}\text{U}$ and ^{14}C dates from corals (Fairbanks *et al.* 2005); (lower) calibration curve for sample 436 from JE0004 showing plateau between 3600 and 3400 BC (Stuvier and Reimer 1993).

There are also the added complexities of dating samples of a marine origin, which need to be corrected for the marine reservoir effect (eg Ritz *et al.* 2008; Reimer *et al.* 2009). The marine reservoir effect (MRE) is essentially a delay in the arrival of atmospheric carbon into the marine food chain by the ocean. Atmospheric carbon is absorbed into the ocean where it is taken out of the food chain by deep ocean currents. Up-welling of these currents along coastlines brings the carbon back into the food chain, up to 400 years after it was first absorbed. This means that marine organisms will be consuming carbon that is 400 years older than the atmospheric carbon, and therefore will give a radiocarbon date 400 years older. Shellfish are the prime example, since they often survive well in archaeological sites and are therefore often used for radiocarbon dating. Variations in up-welling around the globe can affect the MRE, therefore in addition to the global average MRE correction there are local MRE corrections which also need to be accounted for. However up-welling can also change over time, affecting both global and local MRE.

Correction is not a simple process, since it requires that a local correction be applied to the dates. The MRE is calculated using a marine radiocarbon calibration curve rather than an atmospheric one. Although this is a seemingly straight forward process there are a number of factors which need to be considered, not least the location of the nearest calculated Local Marine Reservoir Correction (termed Delta R). This can be potentially problematic, since samples from different depths, or areas with a different pattern of sea currents can affect the correction factor as outlined above. The global average correction value is c.400 years, with local Delta R corrections adding or subtracting from this.

Another key consideration in the pathways by which carbon enters the sample is the type of species which is being measured. As mentioned above, dating marine shell will give a date several hundred years older than a sample such as wood from a terrestrial tree from which the carbon will be derived from the atmosphere. However, different species of marine shellfish have different life cycles, and carbon can enter their shells

through very different pathways. For example a siphon feeding bivalve will likely derive the majority of its carbon from detritus which it is filtering from the water. However a grazing gastropod may inadvertently ingest particles from the substrate which may include particles of fossil carbon, such as from a submerged fossil coral terrace. Anecdotal evidence from within the archaeological community suggests that this has never been a problem; however staff from radiocarbon laboratories strongly advise selecting dating samples from species which are siphon feeders, especially in areas where the substrate is fossil coral (eg Ascough *et al.* 2005). Further studies have also investigated the possibility of secondary mineralization of calcium carbonate on shell post deposition (eg Rech *et al.* 2011) which can introduce contamination to a radiocarbon date if not identified. A further consideration is the fractionation of isotopes within living tissue which increases through trophic pathways; although work has been undertaken suggesting that this depletion is minimal (eg Tieszen *et al.* 1983).

Samples for radiocarbon dating were carefully selected from secure stratigraphic contexts where minimal chance of post-deposition disturbance was likely (eg Christen and Buck 1998). In the case of JE0004 several areas were identified which had likely suffered disturbance and although samples were taken from these areas (in case future research was undertaken in these areas) they were not submitted in this instance. Charcoal was the favoured material for radiocarbon sampling, and where present was sampled. This process involved careful removal of the material from the context using trowel, leaf trowel or modified spoon; the charcoal was carefully wrapped in aluminium foil to protect it, and double bagged in labelled airtight bags. Although identification of charcoal samples was sought, it was not possible in this instance to obtain species identification. Where the samples were large enough some material was retained for later identification, if the opportunity arises.

Where charcoal was not present marine shell samples were taken, again taking every effort to ensure stratigraphic integrity. Fish and mammal bone were present however they were degraded and unlikely to contain enough collagen for dating; therefore samples of these materials were not submitted for dating.

Radiocarbon dating was used first in order to determine the time depth of the excavated sites. An additional radiocarbon date would help to tie in the geoarchaeological trench in the Khur Maadi to the excavated sites. The next stage would be to take marine shell samples from the sites, which were paired with the radiocarbon samples (ie from the same context) in order to determine the temporal resolution of the AAR method.

Radiocarbon dating was then used to investigate the rates of accumulation of JE0004. This was completed by processing a number of radiocarbon samples from throughout the site, and using Bayesian statistics to construction a deposition model. As part of this process Bayesian was also used to calculate the local marine reservoir effect from a number of paired charcoal and marine shell samples.

8.2.2 Amino Acid Racemization

Another dating method which has been extensively developed over the past decade is amino-acid racemization dating (eg Penkman *et al.* 2008; Ortiz *et al.* 2009). Although the scope of material for which this method can be applied to is more limited than radiocarbon dating, for this kind of study it offers great potential. This has been demonstrated in a preliminary study by Demarchi (Demarchi *et al.* 2010), which proved the method can work in hot environments. The decision was taken to build on this initial study and develop the method for use in this project. A copy of Demarchi *et al.* 2010 is included in the Appendix at the back of this thesis.

Amino-acid racemization has potential in this field; it has already been used to great effect to date sites across the world using shell samples taken from a variety of sites (eg Penkman *et al.* 2008). The system has been developed and refined resulting in a robust methodology which works by analysing the intra-crystalline fraction of amino-acids from a closed system. Shell provides this closed system (Penkman *et al.* 2008), whether from egg shell, terrestrial, freshwater or marine gastropods or bivalves. Not all species are suitable for this kind of analysis due to naturally varying levels of amino acids within the shells between species, and the extent to which the shell acts as a closed system. Careful testing is necessary first in order to determine the feasibility of the method. Demarchi *et al.* (2010) has already carried out a preliminary study on the feasibility of a number of Red Sea shells from the Farasan Islands. Her work on five species (*Anadara antiquata*, *Chicoreus ramosus*, *Strombus fasciatus*, *Tibia sp.* and *Trochus dentatus*) showed that two of these species, *S. fasciatus* and *C. ramosus* were suitable for the AAR method.

Of these *S. fasciatus* was selected for further analysis, due to the prevalence of this shell in archaeological shell middens across the islands. An additional incentive to use *S. fasciatus* over *C. ramosus* is that anecdotal evidence from the modern fishermen on the islands suggests that *C. ramosus* is cooked whilst the meat is still in the shell. Although this possibility cannot be discounted for *S. fasciatus* (it is not eaten on the islands any longer) the smaller size of *S. fasciatus* may mean that it does not need as much heating as *C. ramosus*. A factor in this decision are the differences in size and thickness of shell for each species; *C. ramosus* is larger and has a thick shell, it therefore requires a longer heating time to cook and loosen the flesh. *S. fasciatus* is smaller and has a thinner shell, meaning that less heating would be necessary to cook and loosen the flesh; therefore the amino-acids in the *S. fasciatus* shell would not be exposed to heat for as long as those in *C. ramosus* and therefore less racemization would occur.

This work followed the methodology set out by Penkman *et al.* (2008) “Closed-system behaviour of the intra-crystalline fraction of amino acids in mollusc shells” which demonstrated that shells can provide a closed system. This closed system prevents everything except temperature interfering in the racemization process, meaning that it is entirely temperature dependant. The paper also presented a robust method for extracting and measuring amino acids, and testing whether the closed system had been compromised or not. This was a huge step forward for the method which has previously been questioned.

It was hoped that this method could be used to undertake high resolution dating of the stratigraphy of shell mounds. The rate of racemization of amino-acids is temperature dependant, in temperate climates the method has been successfully used as a geochronological dating method for the Quaternary (eg Penkman 2010). In lower latitudes it was hoped that the higher average temperature on the Farasan Islands with a hot season April-October 29.7-38.4°C and mild season November-March 21.4-30.5°C (El-Demerdash 1996), would result in an increased rate of racemization which could be used to pinpoint small changes in time. This would allow the accumulation rate of a shell mound to be assessed, by taking a number of successive samples through the stratigraphy of an excavated site. Calculations suggest that at these higher average temperatures racemization might be approaching equilibrium (David Harker, pers. comm. 2009). However evidence from Penkman suggests that the temperature/depth relationship results in a stabilised (averaged) temperature with increased depth (Penkman pers. comms. 2010).

With AAR being temperature dependant one of the key considerations is whether archaeological heating of the samples has taken place. This could be the result of cooking of edible shellfish or post depositional heating where hearths have affected layers of shellfish immediately below. These questions have been raised for AAR dating (eg Masters and Bada 1977) with attempts to assess these in the lab (Brooks *et al.* 1991).

It was hoped that this method could be used to date shell sites from across the island, in order to assess whether they had accumulated contemporaneously as part of the same phase of accumulation or not. This would be achieved by dating samples obtained from test pits excavated into a number of shell sites across the islands.

AAR dating needs to be calibrated; radiocarbon dating provides the most versatile method to do this with, given that the shell middens are composed predominantly of shell, with pockets of ash/charcoal.

The AAR method works due to the fact that every living organism is composed of amino-acids. Most amino-acids are stereoisomers with levorotatory (L – left) and dextrorotary (D- right) forms, where the majority of living organisms contain the “L” isomer. After death the L-isomers begin to switch or racemize to the R-isomer form; a wide range of factors affect the rate at which this reaction occurs. These include temperature, the presence of water, pH, whether the amino acid is bound or unbound (peptides) and if bound the location in the chain, and the presence of any ionic compounds. To mitigate against the majority of these effects Penkman *et al.* (2008) focused on finding amino acids located in closed environments, sheltered from all but temperature. The intracrystalline structure of shell proved to be just such a protective environment for amino-acids. The authors developed a sequence of processes to release and measure the amino-acids. The majority of amino-acids within a closed system such as this will be bound in peptides; the position of each individual amino-acid within that peptide will influence its susceptibility to racemization.

The basic procedure for AAR preparation follows the methods used by Demarchi *et al.* (2010) in the initial feasibility study for the islands. Suitable specimens of *S. fasciatus* shell were selected from the samples collected during fieldwork and processed according to the protocol set out by Penkman *et al.* (2008). Briefly this constituted cleaning and washing the samples by sonication and rinsing with HPLC grade water; if

necessary secondary deposits of CaCO_3 were removed using a power drill. These deposits were easily identified as they differ in colour and break the smooth flowing contours of the shell. After sufficient cleaning the samples were air dried and then powdered using a pestle and mortar. 20mg of powder was then immersed in 12% NaOCl bleach (50 μL /mg of sample) for 48 hours to remove amino-acids not held within the crystalline structure of the shell. The samples were then rinsed five times with HPLC grade water, then once with HPLC grade Methanol (to ensure complete removal of the bleach) before being air dried and divided into two equal halves.

One half was hydrolysed in 7 molar HCL (20 μL /mg of sample), this would be known as the hydrolysed sample (THAA, bH*or H); during application the vials were flushed with N_2 to reduce oxidation. The samples were then heated to 110°C for 24 hours. The other half was treated with 2 molar HCL (10 μL /mg of sample) and would be the free fraction (FAA, bF or F). Following this, samples were dried in a centrifugal evaporator and rehydrated with 0.01mM HCl (containing an L-homo-arginine standard) before loading into one of two RP-HPLC (reverse-phase high pressure liquid chromatography) machines. These detect the type and amount of amino acids in each sample. The data are then processed (by peak picking) and interpreted. Peak picking is first carried out by a computer program designed to assign certain peaks in the data to specific amino-acids, however this system is not infallible and can often pick the wrong peak. Therefore careful reviewing and manual correction of the data is necessary.

The preliminary trial of material from the Farasan Islands was undertaken by Demarchi (Demarchi *et al.* 2010) and showed that several species of shellfish were suitable for AAR analysis. Their shells contained closed systems and that amino-acids were still present in levels high enough to detect racemization under artificial heating. These are known as *kinetics tests*, whereby a sample of shell is divided into a number of sub-samples. These are heated at a 140°C for incremental time periods, from zero (ie

not heated) until racemization stabilizes. For Demarchi's study three time points were used: zero, twenty-four hours and forty-eight hours (Demarchi *et al.* 2010). As already discussed five species were tested, with two suitable for testing and *Strombus fasciatus* selected for further testing (Figure 111). The *S. fasciatus* samples originated from the Gandeel Peninsula, having been collected during fieldwork in 2006.

The data presented show aspartic and glutamic acids, these were selected over other amino acids because they racemize at a slower and more predictable rate than many others. This can mean that they give a much better result.

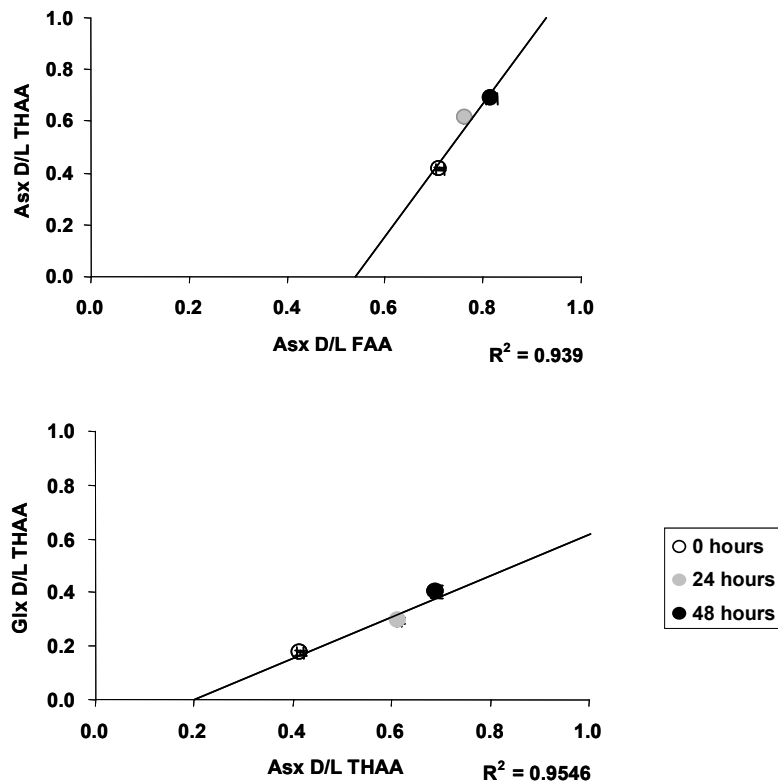


Figure 111: Kinetics for *S. fasciatus*, sample from the Gandeel Peninsula, Demarchi *et al.* 2010.

The AAR program was broken down into four sections to test: against the rangefinder dates; the variability; on a wider range of sites; and finally kinetics and heating experiments would be undertaken to assess the impact of hearths on the shells. The first series of experiments was also

used to assess whether there was any variability in AAR signal between the inner and outer shell. This was accomplished by processing a batch of paired samples, where one sample was taken from the interior of the shell and one from the exterior, and processing these as separate samples. *S. fasciatus* is a species which has not been studied in detail, therefore little is known about the internal structure of the shell, aragonite/calcite composition of the shell, or lifecycle. Had there been time and resources available then it would have been desirable to conduct investigations into these using methods such as thin section analysis or XRF (x-ray fluorescence) analysis.

However there are two methods which can be used to mitigate against any negative effects (such as anomalous dates) that varying levels of calcite/aragonite might have. The first, as described above, is to process samples taken from different portions of the shell and compare the results. The second is to compare the results for each sample against a regression of the kinetics (or heating) tests – any samples which fall away from the regression line are likely to come from compromised closed systems. There can be a number of reasons for this including both those mentioned above. However the closed system could also have been compromised due to a break down in the intercrystalline structure. The makeup of the peptides (ie which amino acids are located next to one another) can also affect the results, with some combinations breaking down faster than others despite being in a closed system. If any samples were found to fall away from the kinetics/heating test regression lines then the sample was discounted due to the high chance of it being compromised.

Sample selection for AAR samples followed a strict protocol. Only *S. fasciatus* were selected for analysis, and these must come from secure contexts where there was no evidence of heating, such as contexts which contained ash or charcoal. Likewise the overlying contexts must not contain evidence for direct heating, since this heat may have permeated down into the layer below accelerating racemization. After anomalous

results from several samples from shallow contexts the selection criteria was modified so that samples must come from contexts of a minimum of 25cm depth, to minimise disturbance and solar insolation. As with the radiocarbon dating, samples must come from contexts which have no signs of post-depositional disturbance. Finally the shells selected had no signs of diagenesis, which could indicate a compromise of the intracrystalline structure of the shell.

In addition the question of erosion or reworking must be addressed. JE0004 showed some evidence for truncation on the coastal side; it has been on the active coastline since deposition at the site began, whereas the sites on palaeocoastlines have not. In addition palaeocoastlines which do not display high energy palaeoshoreline features such as cliffs, and are therefore likely to have been lower energy environments would hopefully be less exposed to the erosive forces at work, as at JE0004. Therefore providing samples are taken from sites not immediately located on modern high energy features such as cliffs the samples stand a greater chance of not being reworked post-deposition.

The selection of samples was therefore governed by a number of rules:

- That the site was not on a modern high energy coastline feature
- The sample came from 25cm depth
- Evidence for archaeological heating must be absent (ie hearths)

8.2.3 Bayesian Statistics

For the Bayesian deposition model the Oxcal program was selected over a number of other possible platforms, including WinBUGS. The decision for the choice was based on the versatility of the tool combined with ease of use and user support available; the latter being a large advantage. The Oxcal Poisson deposition model would be used, since the user can define

the size of depositional events in between radiocarbon dating samples. This adds an extra level of flexibility (or rigidity depending on the values used), and allows for a variety of deposition models to be constructed. The local MRE would also be calculated using Oxcal.

This employs Bayesian statistics, which allows the measured data to be combined with additional knowledge of the sample, for example stratigraphic relationships; this is termed *prior* or *apriori* knowledge (eg Buck *et al.* 1996). Bayes' theorem works on probability, and the resultant output is termed *posterior* probability density or distribution. Bayesian statistics is used in the calibration of single radiocarbon dates (using the Monte Carlo method, where the prior knowledge is the calibration curve), and has been extended to a number of models including deposition modelling. In the case of deposition models the additional *prior* of stratigraphic order and depth can be applied to each sample. The Oxcal Deposition model has the added benefit of having the "Poisson-process" deposition model incorporated into it, whereby the size of depositional events in between radiocarbon dating samples can be defined, but the rate of deposition is random (Ramsey 2008). The larger the size of the deposition unit the more variable deposition is; the smaller the unit the more uniform it is (for example if a meter of sediment accumulated over a year it could be deposited in one event at any time through that year, however 1000 smaller events will be more evenly distributed through time).

Sample selection was dictated by two themes: first the need to resolve the time depth and accumulation processes of the coastal side of the mound (complicated by the unexcavated section at the centre of this area) and secondly to assess whether the inland side of the mound accumulated as part of the same phase of accumulation as the coastal side, or whether it represented a distinct separate phase of accumulation. Following the results of the rangefinder dates, the decision was taken to process two columns of radiocarbon samples from the coastal side, and a spread of samples through the inland site. A further single radiocarbon

date would be processed from charcoal found beneath the skull of the child burial. The two columns of samples from the coastal side would be taken from each side of the unexcavated area, both in order to assess how each side relates to the other and to allow for a comparison between the two columns.

Finally the assessment of the local marine reservoir effect would be integrated into the deposition model dating, whereby two samples (one from each column on the coastal side) would be a paired sample (of charcoal and marine shell).

8.2.4 Luminescence

Luminescence dating was also explored, however the recovery of sufficient quantities of sediment proved difficult. This was primarily due to the distribution of the sediment within the layers of shell, so that there are no easily accessible pockets or layers from which to obtain samples. Combined with the loosely packed nature of shell middens, this would make obtaining stratigraphically secure samples extremely time consuming and hard. Therefore this method was not pursued in this study.

8.3 Results

8.3.1 First Stage: Rangefinder Dating Program

The first stage of the dating program involved obtaining rangefinder dates for the excavated sites in order to determine their time-depths and determine parameters for the rates of deposition. They also allow an assessment of whether the two excavated sites formed as part of the same phase of shell mound building activity or not. A further sample would also be processed from the base of the geoarchaeological trench KM1367, in order to assess the relationship between the sediments in the in-filled bay and KM1057. These rangefinder dates would also be

important in the second phase of dating to help calibrate AAR dating technique. The rangefinder dates were selected from the basal and upper layers of JE0004 and KM1057 and the basal layer of KM1367.

JE0004

Samples were selected from JE0004 after the 2008 field season; they would inform on both the timing of the shell mound and the time depth of the site. This data could and would be used to feed into the subsequent dating strategy.

The samples were selected from the deepest part of the section exposed in 2008, in grid 10G, with an accompanying vertical column of bulk samples also removed to inform on each context. The basal sample, 436, was assumed to be within the oldest deposits of the site in context 2; these were composed of a brown shell bearing humic layer, with inclusions of charcoal from which the sample was taken. This context directly overlay the fossil coral terrace bedrock.

The top sample (485) was taken from context 54, in a position close to vertical above the basal sample. This sample was composed of shell (*Chama reflexa*) because there was not enough charcoal in surrounding contexts. Figure 112 below shows the position of the two samples in relation to the 2008 excavations.

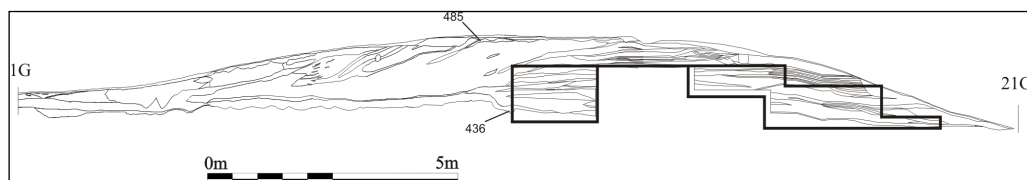


Figure 112: West facing section showing locations of rangefinder dating samples from site JE0004. Box indicates area excavated in 2009.

These samples were submitted to Oxcal and Beta-Analytic for processing, the results are presented in Table 9 below.

8. Temporal Relationships

Lab no	Sample no	Context no	Location on grid	Material	Species	Delta C	Conv. 14C Age	Conv. Error
BETA-255383	485	54	10G	Shell	<i>Chama reflexa</i>	1.6	5010	50
OxA-19587	436	2	10G	Charcoal	na	-24.53	4709	31

Table 9: Conventional radiocarbon results for rangefinder dates from JE0004.

The radiocarbon results presented in Table 9 above are in conventional radiocarbon years, which mean that they are not calibrated. However two problems arise with these dates when calibrating them, the first is the plateau in the radiocarbon calibration curve, the second is which local marine reservoir effect value to use to calibrate sample 485. The first problem can be overcome by using a series of radiocarbon dates and applying Bayesian statistics to them, which will be covered in section 4 of this chapter. The second will be addressed in section 3 also in this chapter. Initially the Delta R value used was one obtained by Southon *et al.* (2002) from the central Red Sea. This was later superseded by a more relevant Delta R value, which is also shown in the table and figure below.

Lab no.	Sample no.	Delta C	Conv. 14C Age	Conv. Error	Delta R	Delta R Error	BP Range 2σ	BP Range 2σ	BP Range 2σ
BETA-255383	485	1.6	5010	50	110	38	5420-5020	na	na
BETA-255383	485	1.6	5010	50	-100	50	5595-5301	na	na
OxA-19587	436	-24.53	4709	31	-	-	5581-5510	5485-5441	5418-5322

Table 10: Table showing the calibrations and intercepts of the two rangefinder dates from JE0004. Note sample 485 was calibrated initially using Delta R of 110±38 (Southon *et al.* 2002) which proved to be inaccurate for these samples. The new value of -100±50 was derived from tests in Stage 3 of this dating program.

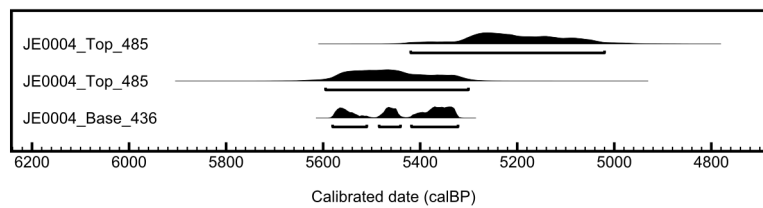


Figure 113: Graphical representation of the intercept probabilities for JE0004 rangefinder dates (Ramsey 2001).

The preliminary results using Southon *et al.*'s (2002) Delta R value suggested a greater temporal extent of the site, especially given the fact that the sample did not come from the youngest deposits of the site. However the subsequent recalibration showed this to be more restricted.

KM1057

Range-finding samples were also taken from the other excavated site of KM1057 for radiocarbon dating; these samples were also selected following the 2008 field season. Site KM1057 is predominantly made up of *S. fasciatus*, a grazing gastropod; consultation with radiocarbon dating expert Tom Higham led to the decision not to submit samples of this shellfish for radiocarbon dating (Higham pers. comm. 2009; Ascough *et al.* 2005). This is due to the risk of older carbonates becoming incorporated into the shell during grazing activity. No charcoal was recovered from KM1057; the only other available material were *Spondylus marisrubri* and *Chama reflexa*, both siphon feeding bivalves which are judged to be at lower risk of incorporating fossil carbon into their shells. Layers of these shells existed close to the base (50cm above base) and top (280cm above base) of this site (Figure 114); samples of *Chama reflexa* were submitted to Beta-Analytic for processing. The results are presented in Table 11, Table 12 and Figure 115.

8. Temporal Relationships

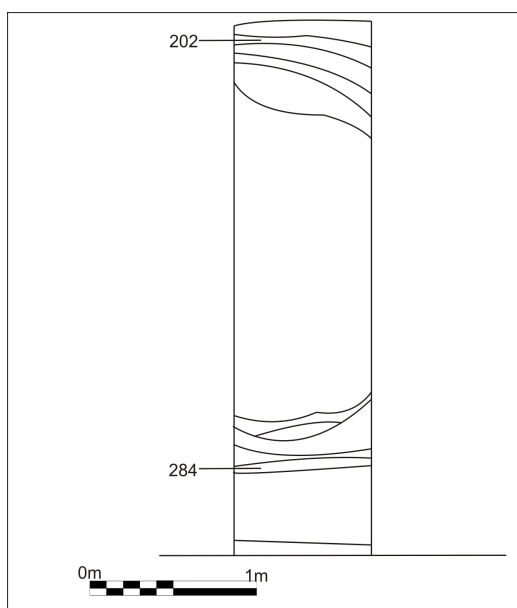


Figure 114: East facing section showing locations of rangefinder dating samples from site KM1057.

Lab Number	Sample number	Context no	Material	Species	Delta C	Conv. 14C Age	Conv. Error
BETA-255385	202	11	Shell	<i>Chama reflexa</i>	2.4	4880	50
BETA-255384	284	2	Shell	<i>Chama reflexa</i>	1.3	4850	50

Table 11: Conventional radiocarbon results for rangefinder dates from KM1057.

Lab no	Sample no	Delta C	Conv. 14C Age	Conv. Error	Delta R	Delta R Error	BP Range 2σ	BP Range 2σ
BETA-255385	202	2.4	4880	50	110	38	4640-4249	
BETA-255384	284	1.3	4850	50	110	38	4621-4237	
BETA-255385	202	2.4	4880	50	-100	50	5515-5110	5100-5079
BETA-255384	284	1.3	4850	50	-100	50	5461-5046	

Table 12: Table showing the calibrations and intercepts of the two rangefinder dates from KM1057.

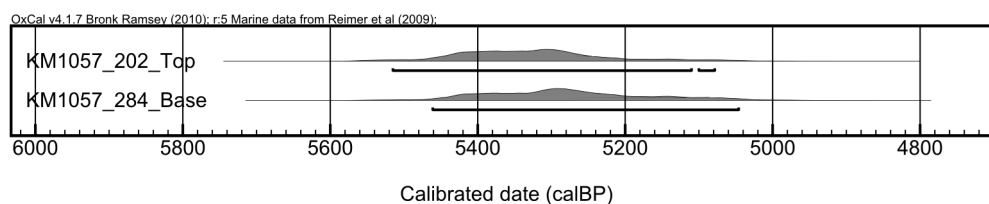


Figure 115: Graphical representation of the intercept probabilities for KM1057 rangefinder dates (Ramsey 2001).

The radiocarbon dates overlap and have large errors. The dates suggest accumulation at the sites between 5461-5079BP (382 years), however this does not take into account the layers above and below the dating samples. Regardless this indicates rapid accumulation, most likely as a result of intensive shellfish processing.

KM1367

A single radiocarbon date was obtained from the base of the geoarchaeological trench KM1367 (Figure 116), in order to determine the relationship between the deposits in the in-filled Khur Maadi Bay and the shell mound KM1057 located at the mouth the bay. An articulated specimen of *Amiantis umbonella* (a filter feeder) was recovered in-situ from the base of the geoarchaeological trench and submitted for radiocarbon dating.

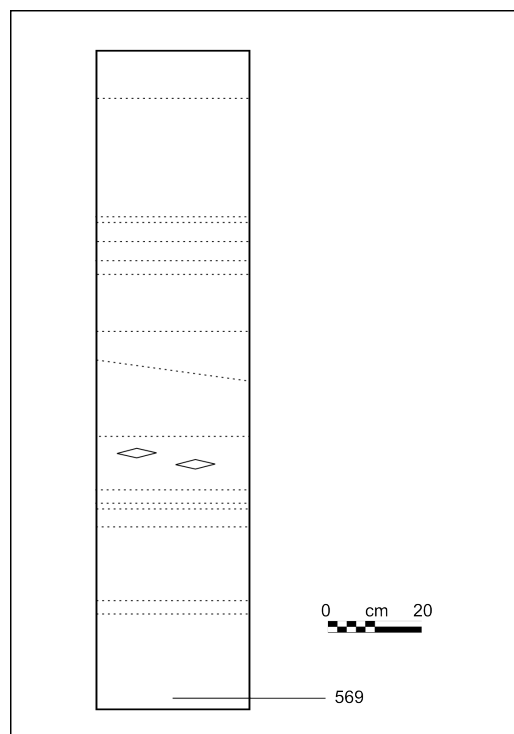


Figure 116: South facing section showing location of rangefinder dating sample from site KM1367.

8. Temporal Relationships

The results show that there was an active shell-bed in the middle of the Khur Maadi bay c.3800-3420 BP (Table 13, Table 14, Figure 117), much more recently than the date for activity at KM1057 of 5515-5079 BP.

Lab Number	Sample number	Context no	Material	Species	Delta C	Conv. 14C Age	Conv. Error
BETA-255386	569	x	Shell	<i>Amiantis umbonella</i>	2.1	3580	50

Table 13: Conventional radiocarbon result for rangefinder date from KM1367.

Lab no	Sample no	Delta C	Conv. 14C Age	Conv. Error	Delta R	Delta R Error	BP Range 2σ
BETA-255386	569	2.1	3580	50	-100	50	3800-3420

Table 14: Table showing the calibration and intercept of the rangefinder date from KM1367.

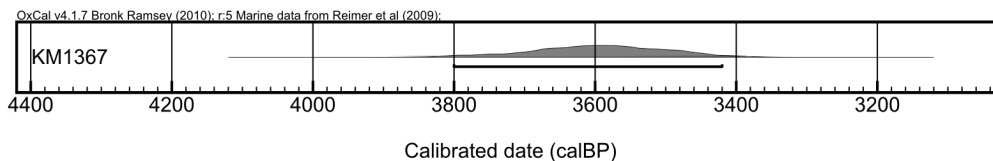


Figure 117: Graphical representation of the intercept probabilities for KM1367 rangefinder date (Ramsey 2001).

Section 1 Summary

The initial results, prior to the calculation of local Delta R suggested that JE0004 had a greater temporal extent than KM1057. For this reason JE0004 alone was selected for investigation with a high resolution dating program (Section 3). Both sites suggest rapid accumulation over a period of up to 300 years for JE0004 and between 0-500 years for KM1057. Interestingly JE0004 is perhaps slightly older, even though it is located on a more inaccessible stretch of coast. This could suggest that shellfish exploitation was intensifying culminating in KM1057, or that the shellfish beds at KM1057 had not developed sufficiently for intensive exploitation whilst JE0004 was accumulating. The fact that both dates are close and fit in with previous dates derived from shell mounds on the islands

suggests that they are the result of a short phase of shell mound building between c.6000-5000BP. The date from the geoarchaeological trench KM1367 provides evidence that the Khur Maadi had an active shell bed at 3800-3400BP. Whether this shell bed was continuously active between c.5000-3800BP is at present unknown, if it was the reason for the cessation of shell mound building in the Khur Maadi must not have been related to local environmental change.

8.3.2 Second Stage: Testing the AAR Method

Temporal resolution

The first priority for AAR testing was to assess the temporal resolution of the method, both for the region and for the shellfish species selected. This would be achieved by selecting samples of *S. fasciatus* from the same contexts which had already been radiocarbon dated in the range-finding test. This would allow a comparison of the two techniques, and an assessment of the resolution of the AAR method in this region.

Samples were first taken from KM1057 and KM1367 because of the larger difference in age shown by the radiocarbon range-finder dates and lack of evidence for archaeological heating at KM1057. Following this samples from JE0004 were processed to compare to the radiocarbon range-finding dates. A key consideration in the decision to test the method at three sites is the differing settings at each site. KM1057 is a large shell mound with a very homogenous matrix of predominantly *S. fasciatus* with little evidence for heating, KM1367 is a natural death assemblage, and JE0004 is a shell mound with a complicated stratigraphy with much evidence for burning.

KM1057 and KM1367

The first samples to be processed came from near to the base of KM1057 and the base of KM1367 (Figure 118 and 119) in order to determine the

resolution of the method against the rangefinder dates from this area. The rationale for selecting these samples was that the shellfish came from the same environment; the radiocarbon dates also suggest that the sampled contexts were sufficiently far apart in date that the extent of racemization between the samples could be assessed. The KM1367 date is much younger than the date modelled by the DNA Recovery Rate Calculator (Harker pers. comm. 2008) for the maximum temporal extent of the method, making it useful as a comparison against the KM1057 sample.

To test for any difference between the internal and external fraction of the shell pairs of samples were processed. Each pair consisted of a sample from the inner whorl and outer whorl of the shell to determine if there was any discernable variation in racemization between the two areas of the shell.

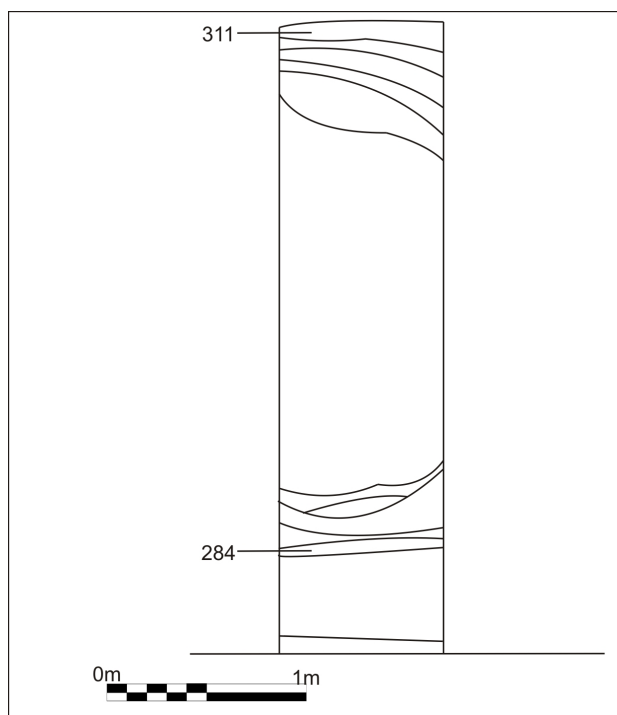


Figure 118: Location of AAR samples from KM1057.

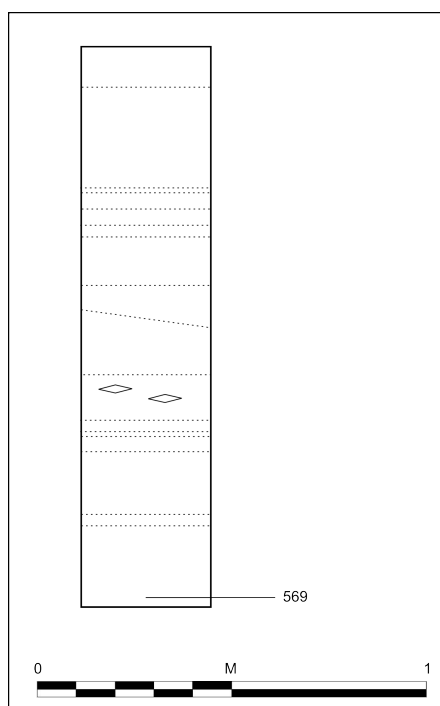


Figure 119: Location of AAR basal sample from KM1367.

The results of this first test are shown below in Figure 120.

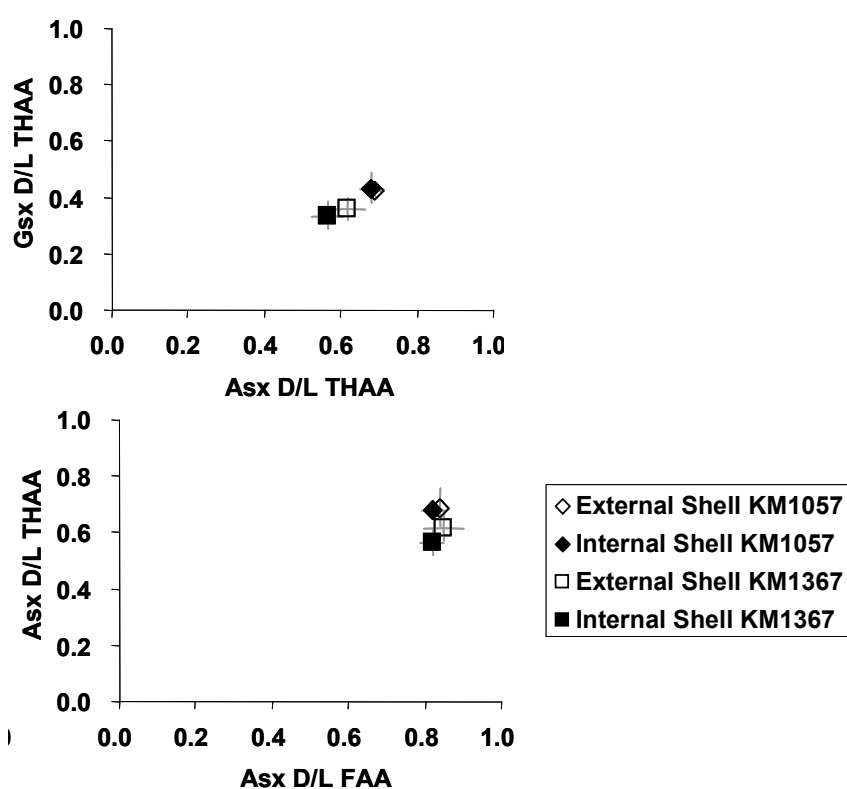


Figure 120: Initial AAR test of shells from the basal contexts of KM1057 and KM1367; internal and external samples of shell are shown. On the left THAA of Asx and Glx are plotted against each other; on the right FAA and THAA for Asx are plotted against each other. Error bars are to two standard deviations.

The graphs above show internal and external shell fractions plotted against each other. The units are fractions of amino acids, where Asx is asparagine/aspartic acid, and Gsx is glutamine/glutamic acid; the fractions are calculated by dividing the amount of dextrorotatory (D) isomers by the amount of laevorotatory (L) isomers. FAA is the free amino acids and THAA is total hydrolysable amino acids, in relation to the way the samples were processed. The results from the internal and external samples of shell showed no significant statistical difference between the fractions with the notable exception of the Asx D/L THAA samples from KM1367. These samples showed a clear statistical difference which can be seen in Figure 120.

The data also show a clear statistical difference between samples from KM1057 and KM1367. The notable exception to this was for Asx D/L FAA, which showed no statistical difference between the samples (Figure 121). This demonstrated that method could be applicable to this region if the shells were carefully selected from similar contexts and THAA favoured over FAA. From these results samples would be selected from the same area of the shell to try maintain consistency. For ease of possessing the exterior portion was chosen since it is much easier to powder than the internal whorls.

The following graph has the Gandeel Peninsula Kinetics (after Demarchi *et al.* 2010) superimposed on the KM1057 against KM1367 results, showing an R value confidence of c.91% for the plot of D/L THAA for Glx and Asx. The R value for Asx THAA against FAA is much lower (c.70%), but is still within two standard deviations; however as described above the Asx FAA values show no statistical difference and although used in previous studies (eg Demarchi *et al.* 2010) they will not be relied upon to differentiate between the ages of sites.

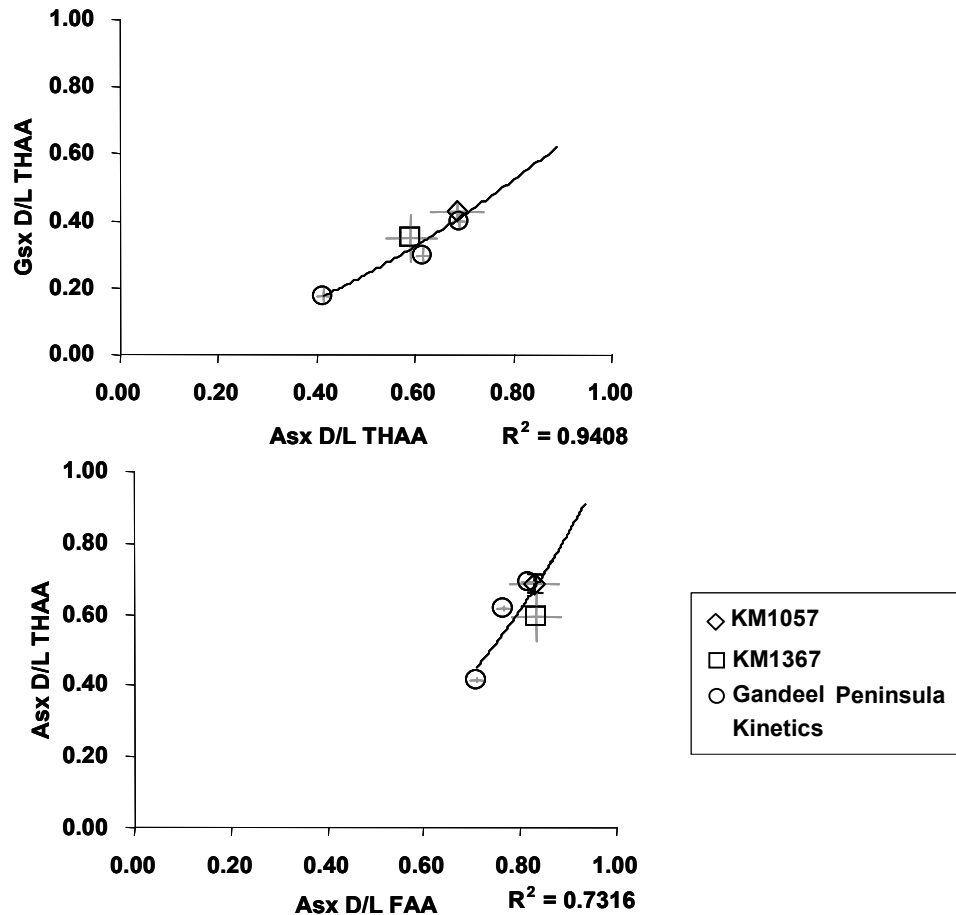


Figure 121: Left – Asx and Glx D/L THAA for KM1057 and KM1367 plotted against Gandeel Peninsula Kinetics (Demarchi *et al.* 2010); right – the same but with Asx D/L THAA and FAA plotted. Error bars are to two standard deviations.

A further four samples (sample 311) were processed from the top of KM1057 to determine whether the resolution of the method was sufficient to differentiate between the base and top of the site (Figure 122). The radiocarbon dates had already demonstrated that the initiation and termination of the site occurred within the error of the method.

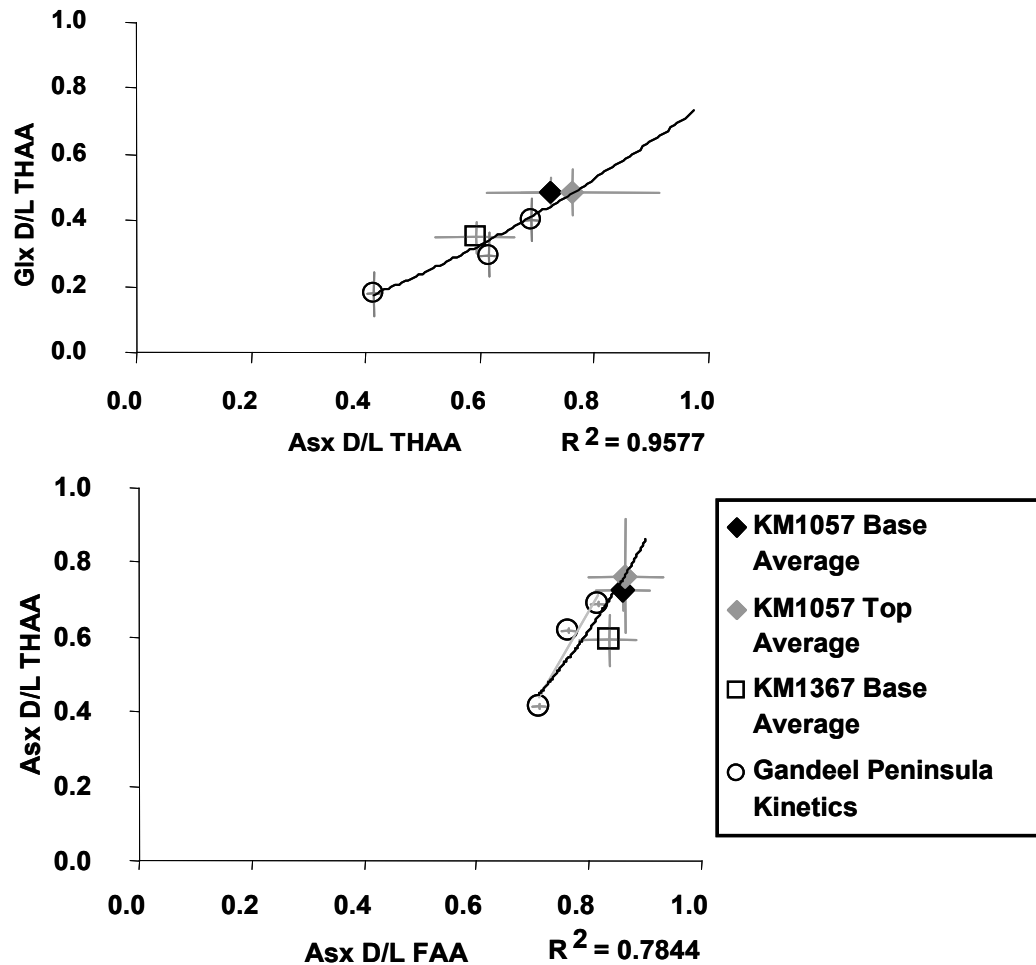


Figure 122: Left – Asx and Glx D/L THAA for KM1057 top and base and KM1367 plotted against Gandeel Peninsula Kinetics (Demarchi *et al.* 2010); right – the same but with Asx D/L THAA and FAA plotted. Error bars are to two standard deviations.

The results for sample 311 from the top of KM1057 had a much greater associated error for Asx D/L THAA, unlike the previous samples. However the average value was centred close to that of the basal sample, suggesting a degree of conformity. There is no significant statistical difference between the samples for Asx D/L FAA or Glx D/L THAA; however there is significant difference between the Asx D/L THAA values. When viewed on the graph this difference was more than outweighed by the large standard deviation of sample 311.

JE0004

A number of samples were taken from JE0004 in order to assess the potential of AAR to provide a relative chronology for the site. Samples

were selected from the centre of the mound at base and near to the top, and at both ends of the trench, from grid squares 1G and 20G. The deposits in 1G were sufficiently deep to allow two samples (upper and base) to be processed, whereas at 20G the deposits were thin and only allowed 1 sample to be collected (Figure 123).

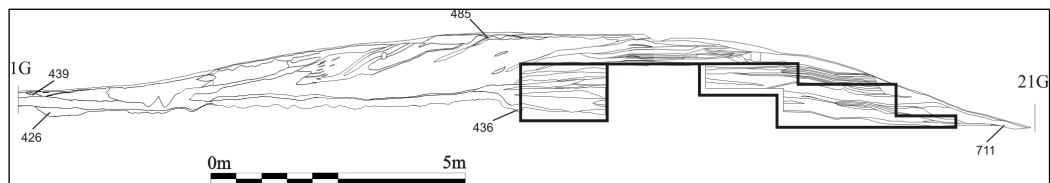


Figure 123: West facing section through JE0004 showing locations of AAR samples. Boxed area excavated in 2009.

The rationale for selecting samples from these locations was to first to test the method directly against the radiocarbon dates with samples 485 and 436. A secondary objective was to test the sensitivity of the method at the periphery of site JE0004, with a single sample from the coastal southern side (sample 711) and two samples, one from the base and one from the top on the landward side in shallow deposits. The results are shown in Figure 124.

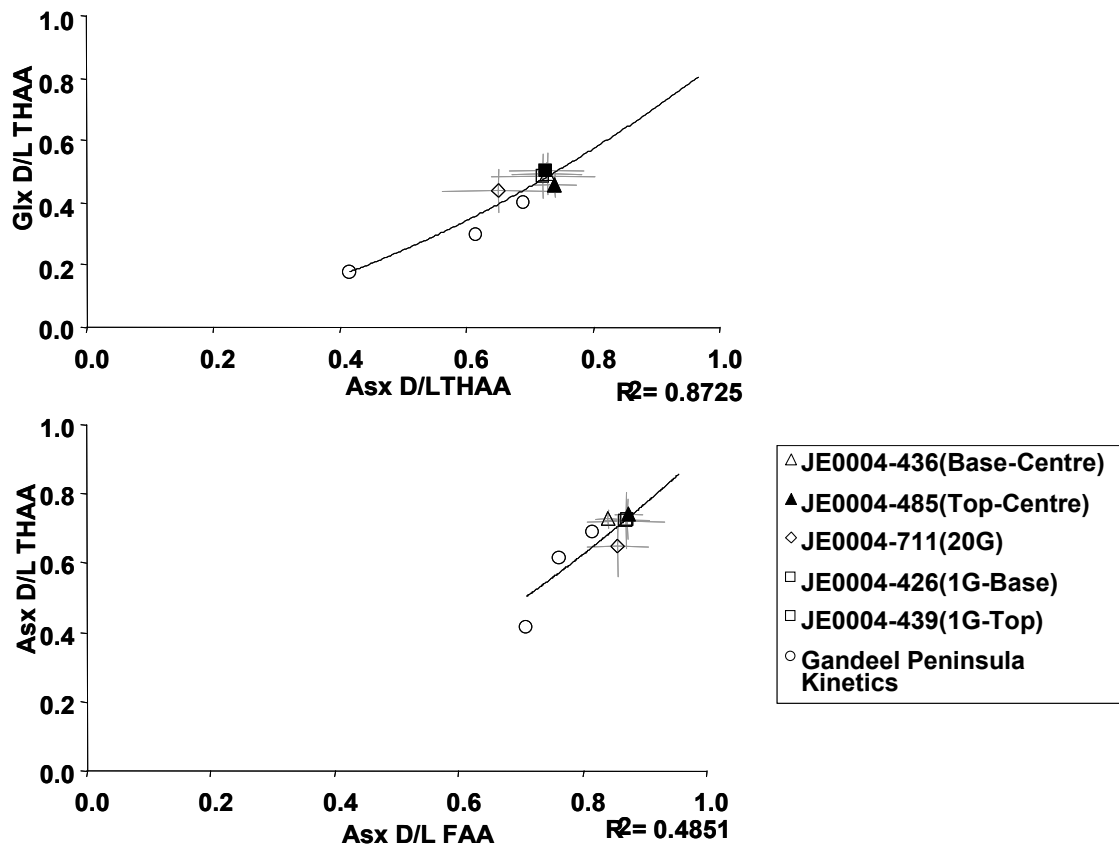


Figure 124: Left – Asx and Glx D/L THAA for JE0004 AAR samples plotted against Gandeel Peninsula Kinetics (Demarchi *et al.* 2010); right – the same but with Asx D/L THAA and FAA plotted. Error bars are to two standard deviations.

The data are clustered with the exception of 711 which shows a statistically significant lower value. Sample 711 was taken from close to the edge of the mound on the seaward side and could have been reworked or be genuinely younger than the rest of the mound. There is no statistical difference between the other samples.

AAR Variability Test

The first experiment showed that the method had potential, but raised some questions about inter-sample variability. The next step was to determine the variability between samples from the same context, in order to determine whether there were any improvements which could be made for sample selection. Unpublished work by Joanne Powell (pers. comm. 2009) suggests that a minimum of five samples is needed to

overcome variations between samples. This figure was derived from the entire dataset of AAR samples from the BioArch AAR (NEAAR) laboratory.

It was decided that ten samples per context should be tested in order to determine whether the variation in smaller sample sizes was random variation, perhaps specific to that context, or whether there was a larger variability within the amino-acids of this species which had not been detected within the tests already carried out. Four sets of ten samples were selected for processing; a basal sample was selected from JE0004, a top and basal sample from KM1057, and a basal sample from KM1367 (Figure 125). These samples were carefully chosen, avoiding areas showing evidence of burning, and being at least 25cm below the surface to allow for thermal diffusion of solar radiation. The variability shown in sample 439 which was only 10cm below the surface and within charcoal bearing deposits strongly influenced these selection criteria.

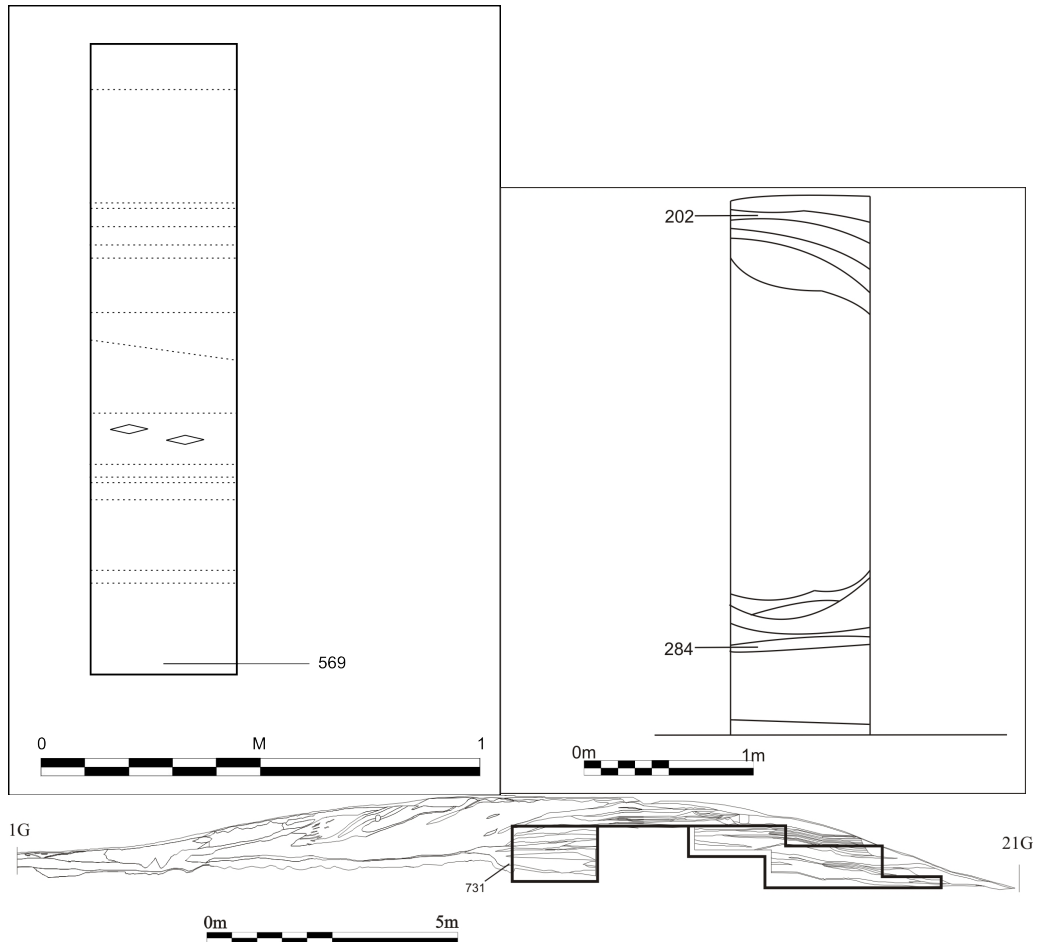


Figure 125: AAR variability test sample locations from JE0004 (bottom), KM1367 (top left) and KM1057 (top right).

These samples displayed relatively low variation (Figure 126); despite the distinction between KM1367 and the other sites becoming less clear in this instance there is still a statistically significant difference between KM1367 and the other sites.

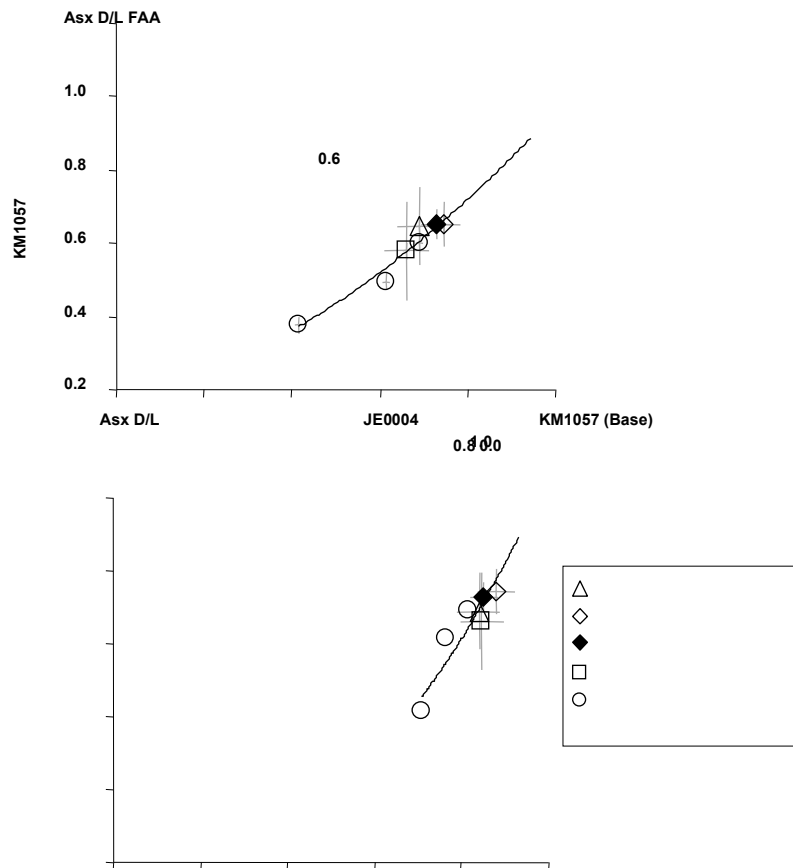


Figure 126: Left – Asx and Glx D/L THAA for the AAR variation test plotted against Gandeel Peninsula Kinetics (Demarchi *et al.* 2010); right – the same but with Asx D/L THAA and FAA plotted. Error bars are to two standard deviations.

This experiment showed that for the samples taken from the Khur Maadi there was lower variation than that of JE0004. Factors contributing to this could be the proximity of the samples to hearths. The samples taken from KM1057 were not thought to be located close to hearths because of the lack of ash in the locations of the samples. This does not discount that the shells had been heated prior to deposition, but it does mean that they would not be exposed to heat after deposition, especially prolonged heat if a hearth pit was frequently used/re-used. At JE0004 it appears as if burning activity has affected much of the site, since ash and charcoal are present in numerous contexts. Even those layers of *S. fasciatus* which are “clean” with few traces of material other than *S. fasciatus* are often sandwiched between hearth layers composed predominantly of ash and charcoal.

The higher variation recorded for KM1367 could be the result of reworking events, since there is unlikely to have been any anthropogenic heating to shells in this natural assemblage.

When the tests of ten are plotted against their associated radiocarbon dates they do suggest a broad agreement (Figure 127).

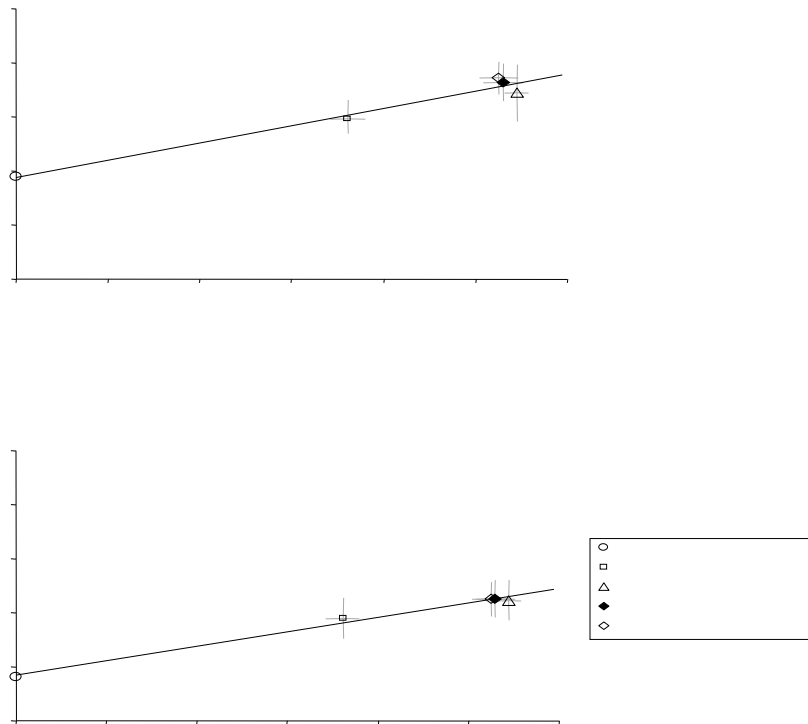


Figure 127: Radiocarbon dates (years BP) plotted against THAA Asx D/L. A trend-line has been added given a calibration equation. Radiocarbon dates derived from marine shell are calibrated using -100 ± 50 years as the Delta R correction.

Section Summary

The AAR tests have built on the preliminary work of Demarchi *et al.* (2010) showing that this method can be used in hotter climates.

Unfortunately the resolution was not as high as had been hoped for giving a high error comparable with radiocarbon dating for this period. With the added uncertainty from the fraction of shell (inner versus outer) and the possibility of archaeological heating of the shell the error can be further

increased. However plotting the paired samples against their associated radiocarbon dates offers a good match. Although this test has proved the method to be unsuitable for high resolution dating in this instance, it shows potential for use in testing if sites originate from the same phase of activity.

8.3.3 Third Stage: Deposition Model

Rate of Formation

The third part of the dating program had the specific focus of dating the internal structure of a shell mound and constructing a deposition model (eg Stein *et al.* 2003). This would allow for a reconstruction of the rate of formation of the site, informing on the formation processes at work. This involved implementing a dating program using radiocarbon dating of selected samples from within the stratigraphy of the shell mound, and creating a deposition model using Bayesian statistics.

The homogenous nature of the deposits combined with the closely overlapping rangefinder radiocarbon dates made KM1057 less suitable for such high resolution testing. The complex stratigraphy of JE0004 with two distinct formation processes offered a greater potential for a high resolution program. The initial radiocarbon dates also suggested a greater date range when using the modern Local Marine Reservoir Effect (LMRE). Therefore the decision was taken to undertake a high resolution dating program of JE0004.

Numerous dating samples were extracted during excavation allowing some flexibility in which samples could be chosen for processing. Twenty samples were selected for radiocarbon dating and submitted to the Oxford Radiocarbon Accelerator Unit (ORAU), Beta Analytic and the Scottish Universities Environmental Research Centre (SUERC). Unfortunately three samples failed (440, 472 and 485) and it was only possible to resubmit one (485), these therefore leave a gap in the dating

program. All failed samples were charcoal samples which failed due to low yields of carbon, despite flotation and weighing in the lab prior to submission.

When the radiocarbon dates were first inspected there were a number of samples which did not fit into the chronology well, and suggested reworking or contamination. However these were all samples derived from marine shell, suggesting that the problem lay not in the samples but in the calibration. The modern values for Delta R (Local Marine Reservoir Correction) were clearly not suited to these samples; this could either be due to the difference in habitat between the site and the samples which had been used to calculate the modern Delta R, or it could be because currents in the Red Sea have changed over time.

In order to overcome this problem it was decided to process a number of paired samples of charcoal and marine shell from the same secure archaeological contexts in order to definitively calculate the Delta R value for these archaeological samples. This will be presented first, followed by the results of the deposition model.

Delta R Test

Due to the lack of charcoal in some sections of the site, it was necessary to submit samples of marine shell for radiocarbon dating. As already described great care was taken to select shellfish species which were siphon feeders as opposed to grazers, in order to minimise the chance of anomalous dates due to the incorporation of fossil carbon into the shell (eg Ascough *et al.* 2005; Deo *et al.* 2004). However this was not the only consideration which needed to be addressed. The well documented phenomenon of the Marine Reservoir Effect (MRE) is something which could impact on the dating program (eg Ascough *et al.* 2005).

The Local Marine Reservoir Effect for the Red Sea has been calculated by in a number of studies (eg Southon *et al.* 2002; Felis and Pätzold

2004; Cember 1989; Siani *et al.* 2000); however these focus on modern specimens from the last few hundred years. Unconformities were noted in the radiocarbon dates between the dates derived from charcoal and those of marine origin calibrated using the modern Delta R derived by Southon *et al.* (2002). This was particularly visible in the deposition models, where stratigraphic relationships highlighted the difference between marine shell and charcoal radiocarbon dates.

It was therefore decided to undertake a brief assessment of the local MRE during the period of accumulation of the shell middens. Work by Edelman-Furstenberg *et al.* (2009) suggests increased stratification of deeper water in the central Red Sea between 5700-4400BP, suggesting weaker up-welling. However this is countered by an apparent abundance of nutrients in the upper layers of the water. This means that the variation in Delta R could also be due to the different habitat that the samples came from, not just past changes in ocean circulation (eg Staubwasser and Dulski 2002; Art *et al.* 2003; Ashckenazi-Polivoda *et al.*, 2010; Edelman-Furstenberg *et al.* 2009; Trommer *et al.* 2010). To test this it would be necessary to test the Delta R for the same period from other sites with different local environments. However this is beyond the remit of this study due to funding limitations, but it would make a very interesting case study for future research.

The method chosen to test the Delta R is the paired samples method (Ascough *et al.* 2005). Paired samples of charcoal and shellfish from the same contexts were submitted for radiocarbon analysis by SUERC (Table 15). These showed an MRE difference of c.300 years, 100 years less than the modern global average. The calibration using the global average mimicked this difference (Figure 128 and Table 16) however the application of a -100 ± 50 Local correction resulted in a much better fit. This contradicts the modern values of $+110 \pm 38$ and $+127 \pm 54$ for the central Red Sea (Southon *et al.* 2002; Cember 1989) which are amongst the lowest for this area. It also seems to contradict the data for greater stratification during this period (Edelman-Furstenberg *et al.* 2009), which

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could indicate local variations in currents or be indicative of the nature of the ecosystem from which the shells originate.

Lab. No.	Sample no.	Context No.	Grid Squ.	Material	Species	δC	Conv. 14C Age	Error
SUERC-26624 (GU-20224)	1432C	11	12F D /12F B	Charcoal	na	-24.6	4705	35
SUERC-26625 (GU-20225)	1218S	19	12FB	Shell	<i>Pinctada nigra</i>	1.3	5005	35
SUERC-26621 (GU-20220)	1388C	70	14F D	Charcoal	na	-24.9	4675	35
SUERC-26622 (GU-20221)	1388S	70	14F D	Shell	<i>Pinctada nigra</i>	0.7	4980	35

Table 15: Table of charcoal/shell paired radiocarbon samples from JE0004 (Ramsey 2001).

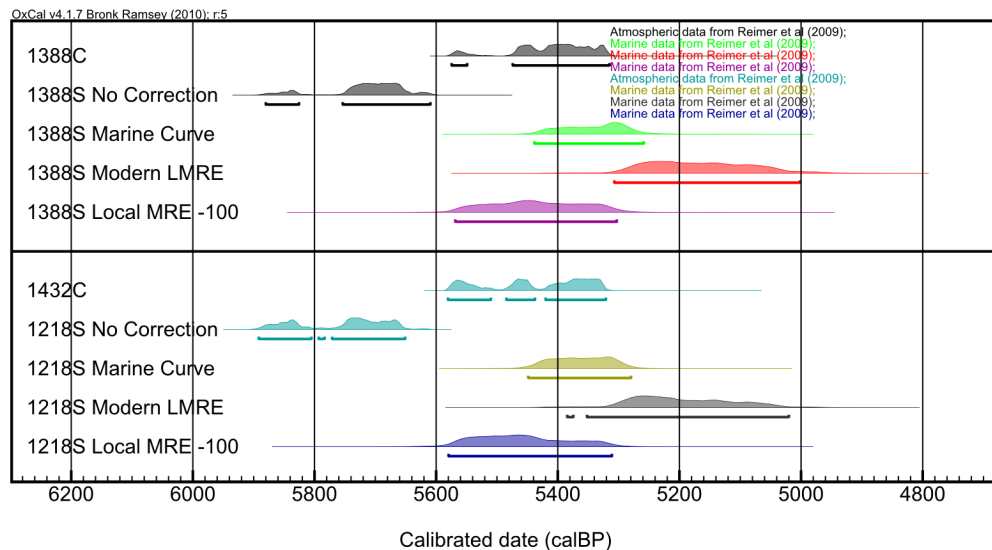


Figure 128: Radiocarbon Delta R calculation. Charcoal (1432 C and 1388C), marine shell (1218S and 1388S) uncorrected, corrected for global marine reservoir effect, and corrected with local MRE of -100 ± 50 (Ramsey 2001).

Sample (Correction used)	Date Range	
1388C	5575	5315
1388S No Correction	5880	5610
1388S Marine Curve	5439	5259
1388S Modern LMRE	5307	5002
1388S Local MRE -100	5569	5303
1432C	5581	5321
1218S No Correction	5892	5651
1218S Marine Curve	5449	5280
1218S Modern LMRE	5385	5020
1218S Local MRE -100	5580	5311

Table 16: Date ranges from modelled using Oxcal (Ramsey 2001).

This test has proved useful for calibrating the radiocarbon dates derived from marine shell, particularly those in the JE0004 sequence. Prior to this test the preliminary rangefinder dates suggested a much broader time depth for JE0004.

The error involved in dating this period must be considered in relation to these results, especially when considering that the difference between modern Delta R value and calculated archaeological Delta R value is only 200 years. This is well within the range (postior distribution) for individual radiocarbon dates and it may be that this error is masking the difference between the MRE values. However this experiment is useful in demonstrating that a difference may exist, especially when taken in conjunction with evidence from previous studies (eg Edelman-Furstenberg *et al.* 2009) which suggest that the circulation of the Red Sea has undergone change which will potentially affect MRE values. In addition the circulation around the Farasan Islands where the water is often very shallow with convoluted channels and bays is in contrast to the more open coastline on the opposite site of the Red Sea from which the modern MRE values were derived.

Rates of Formation

Bayesian modelling was seen as a powerful tool to better understand the formation processes and rates of accumulation of a large shell mound. Of the two excavated sites, JE0004 was selected for this analysis, due to the

more complicated stratigraphy, and greater time depth demonstrated by the rangefinder dating.

The selected samples are shown in Figure 129 and 130 (location of samples on section drawing), showing where processed samples originate from in the shell mound. A series of samples were selected on both sides of the mound in order to better understand the time-depth of different areas of the site. Since the centre of the mound has not been completely excavated samples were taken on both sides of the unexcavated area from contexts whose relationship is not immediately apparent. This is complicated by the unconformity noted in grid 15G of the section. Above this a series of dates have been taken through the sequence in order to help determine the temporal resolution of the upper deposits. Unfortunately the three failed samples were from the latest deposits of the sequence with only 485 reprocessed, meaning that it is not possible to resolve the final stages of deposition at this time. An additional sample was also recovered from beneath the skull in the child burial, perhaps giving an indication of the final phases of use of the site (Figure 130).

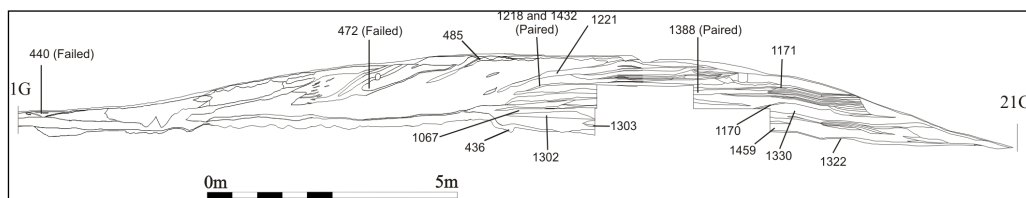


Figure 129: Location of radiocarbon dating samples from JE0004; numbers are sample numbers (west facing section).

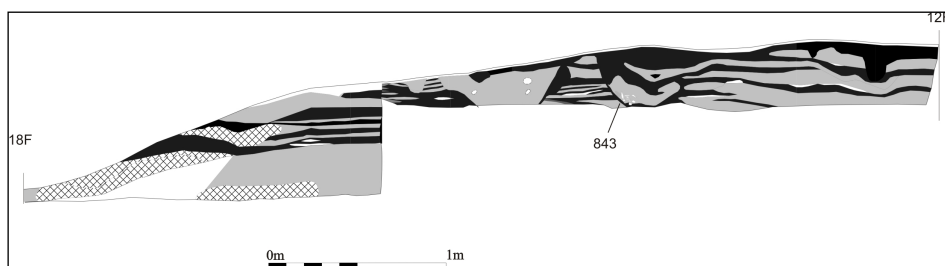


Figure 130: Location of radiocarbon dating sample from beneath child skull (east facing section).

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The dates produced by the dating program are presented in Table 17, and show a spread of dates from 5310-5040BP (sample 843) to 5600-5460BP (sample 1322); just over 600 years. The calculated local MRE value presented above was used to adjust radiocarbon dates derived from marine shell (samples 485, 1218, 1221 and 1388).

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[illegible]

These dates are broad and there is much overlap between them, with the notable exception of sample 843 which originated from charcoal lining the cut of the child burial. In order to gain a better understanding of how the dates relate to each other, and how the site accumulated Bayesian statistics was employed.

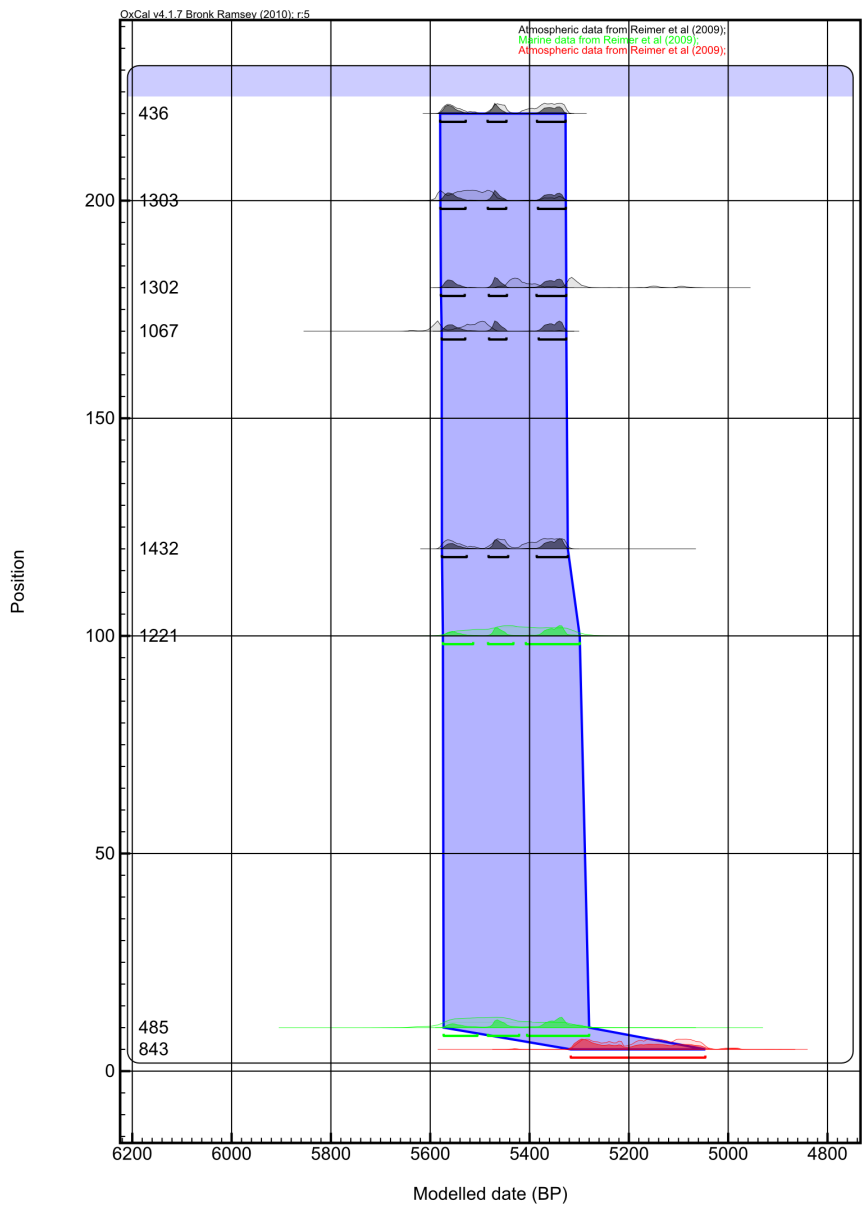
This method was utilised to create deposition models using the dates and *a priori* knowledge of the stratigraphy to help determine rates of deposition at the site. Vertical depth was first used based on the section drawings; however this had the drawback of being non-representative of total accumulation since much of the site accumulated horizontally.

The vertical deposition is characterised by thin layers, often only a centimetre or so thick; whilst the horizontal deposition appears to be composed of larger events up to half a meter to a meter thick. This results in some discrepancies, where the depth of the deposit is not necessarily indicative of the age, since deposition is not necessarily vertical. Therefore the deposition model has been constructed using the depth of deposited layers between samples (Table 18), rather than their distance from the surface.

Inland Side of Mound					Coastal Side of Mound				
Lab. No.	Sample no.	Depth Below Surface (cm)	Depth Between Samples (cm)	Cumulative Depth (cm) between samples	Lab. No.	Sample no.	Depth Below Surface (cm)	Depth Between Samples (cm)	Cumulative Depth between samples (cm)
Beta - 267667	843	30	0	0					
BETA-255383	485	10	10	10					
SUERC-26623 (GU-20223)	1221	30	90	100					
SUERC-26624 (GU-20224)	1432C	55	20	120					
SUERC-26625 (GU-20225)	1218S	55	0	120					
					Beta - 267670	1171	25	10	130
					SUERC-26621 (GU-20220)	1388C	43	10	140
Beta - 267668	1067	110	50	170	SUERC-26622 (GU-20221)	1388S	43	0	140
Beta - 267671	1302	116	10	180	Beta - 267669	1170	53	40	180
Beta - 267672	1303	130	20	200	Beta - 267674	1330	65	15	195
OxA-19587	436	144	20	220	Beta - 267675	1459	120	30	225
					Beta - 267673	1322	90	0	235

This has resulted in the following deposition model for the two sides of the mound, inland and coastal (Figure 131). This was created using the Oxcal program (Ramsey 2008), which has a deposition model which can be applied to dating samples. The average depth of deposit is 10cm on the coastal side of JE0004; therefore this value has been used. There are contexts both smaller and larger than this, and variations in the size of depositional event were explored; two outcomes using these variations can be seen below in Figure 131. The figure on the left shows a model which accommodates all possible intercepts of each radiocarbon date, even where the probability is low. In contrast the right hand figure discounts a number of these outlying intercepts and in the case of sample 843 even those which are not outliers, favouring a faster accumulation rate.

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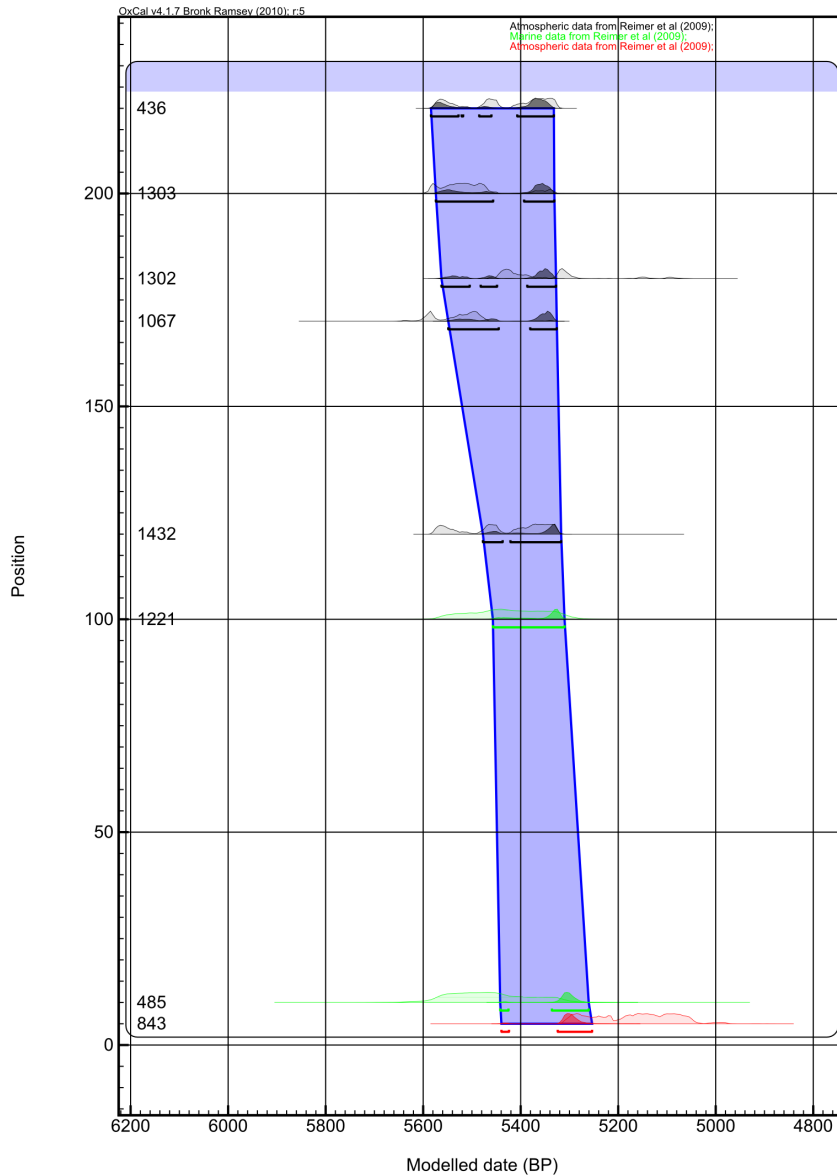


Figure 131: Deposition modelling tests for the inland sequence of JE0004 – upper is P0.001; lower is P0.1 (Ramsey 2008).

The next figure (Figure 132) shows a compromise between the two, notably discounting some of the outliers for samples 1221 and 485 whilst including those for 1432 and 843.

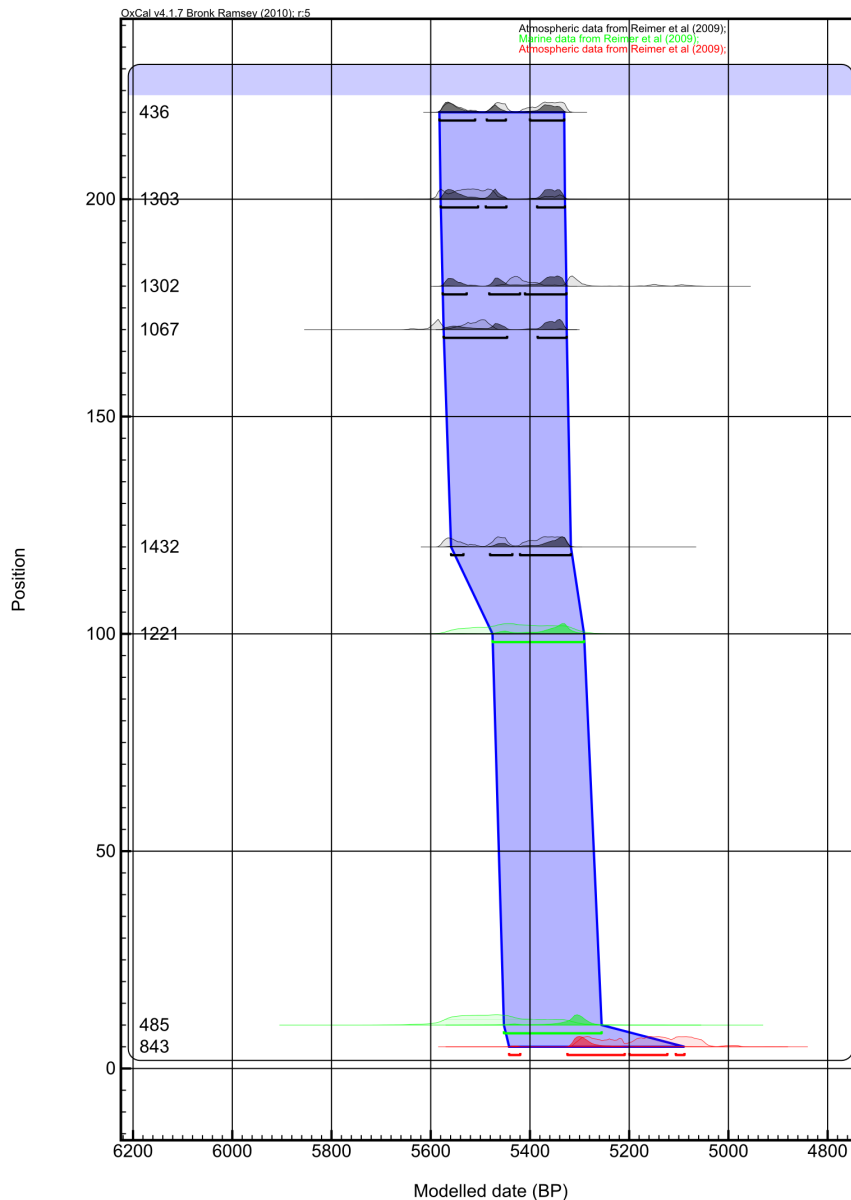
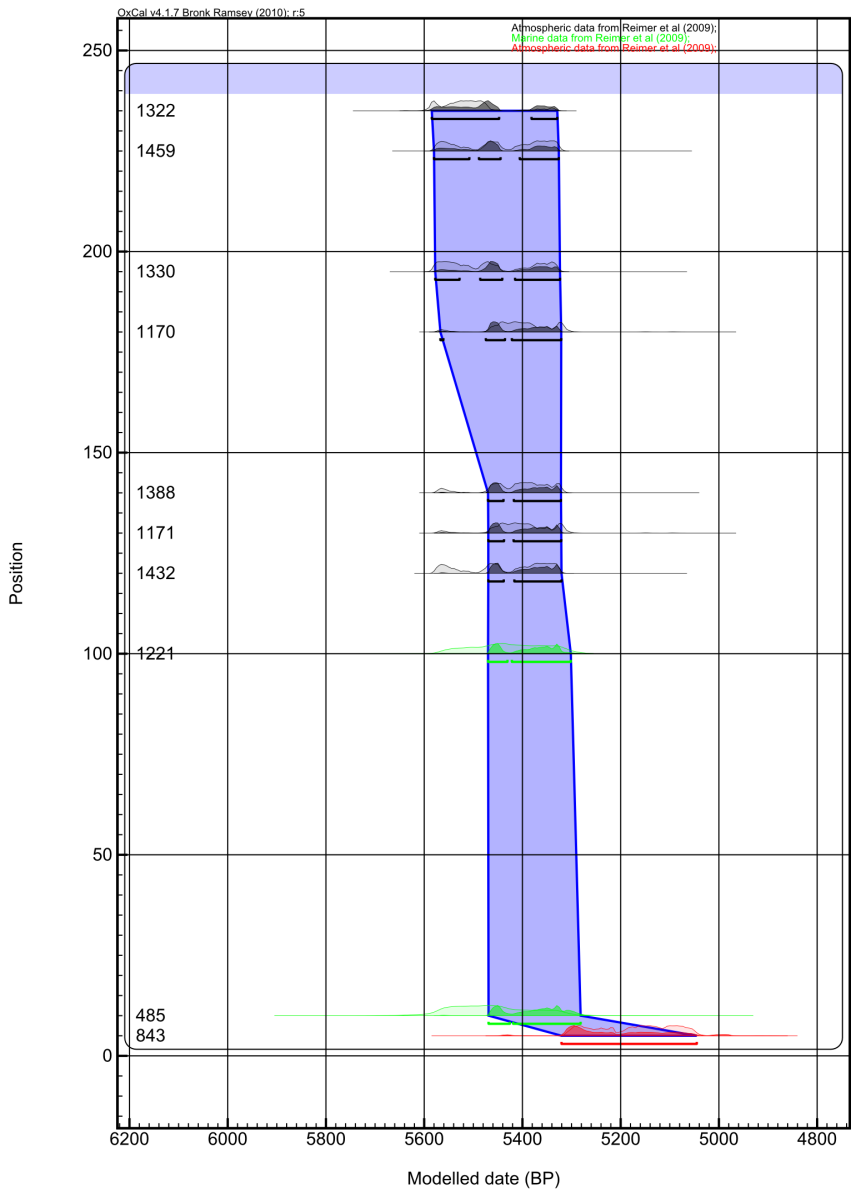


Figure 132: Deposition model for inland radiocarbon sequence from JE0004, P0.01 (Ramsey 2008).

A similar pattern can be seen in the deposition model for the coastal sequence from JE0004. The first two models (Figure 133) show some variation, notably for samples 1330, 1170 and 843.

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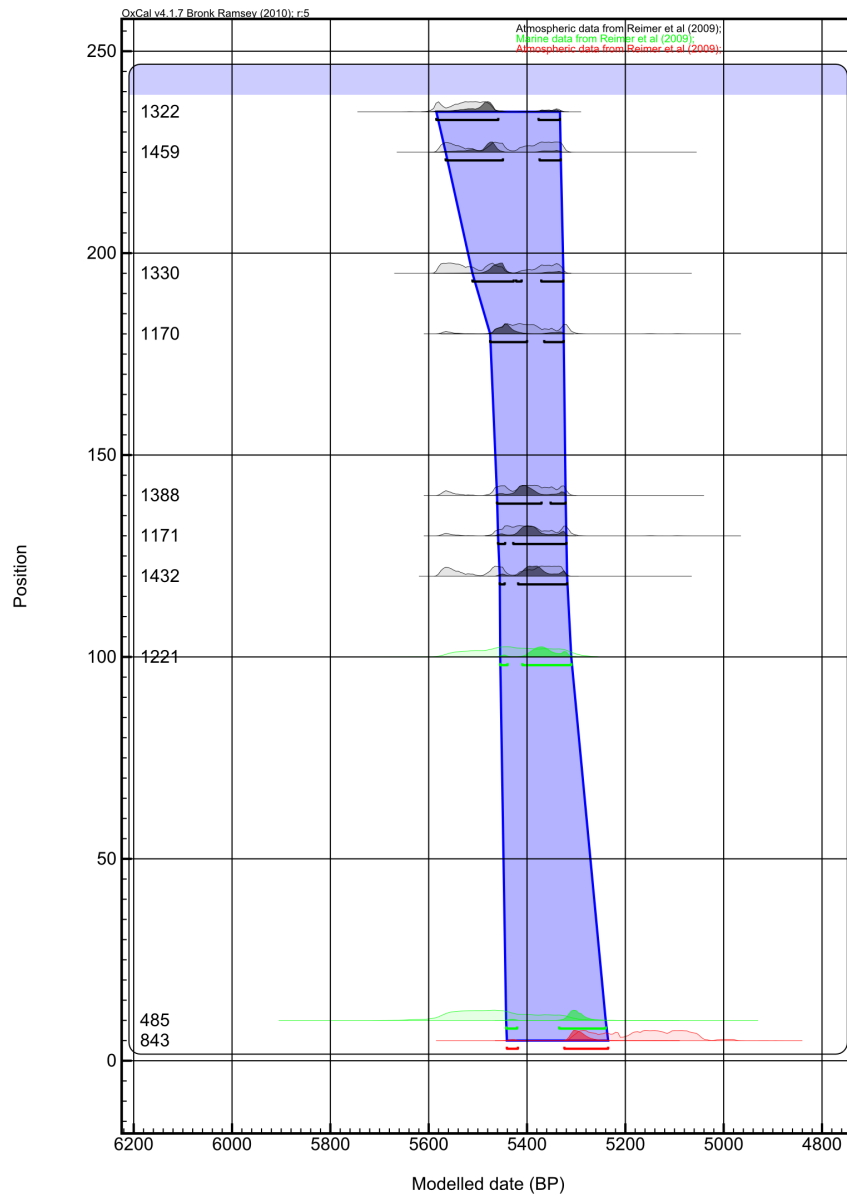


Figure 133: Deposition modelling tests for the coastal sequence of JE0004 – upper is P0.001; lower is P0.1 (Ramsey 2008).

Figure 134 shows the model using a Poisson value of P0.01 which offers a compromise between the two models above.

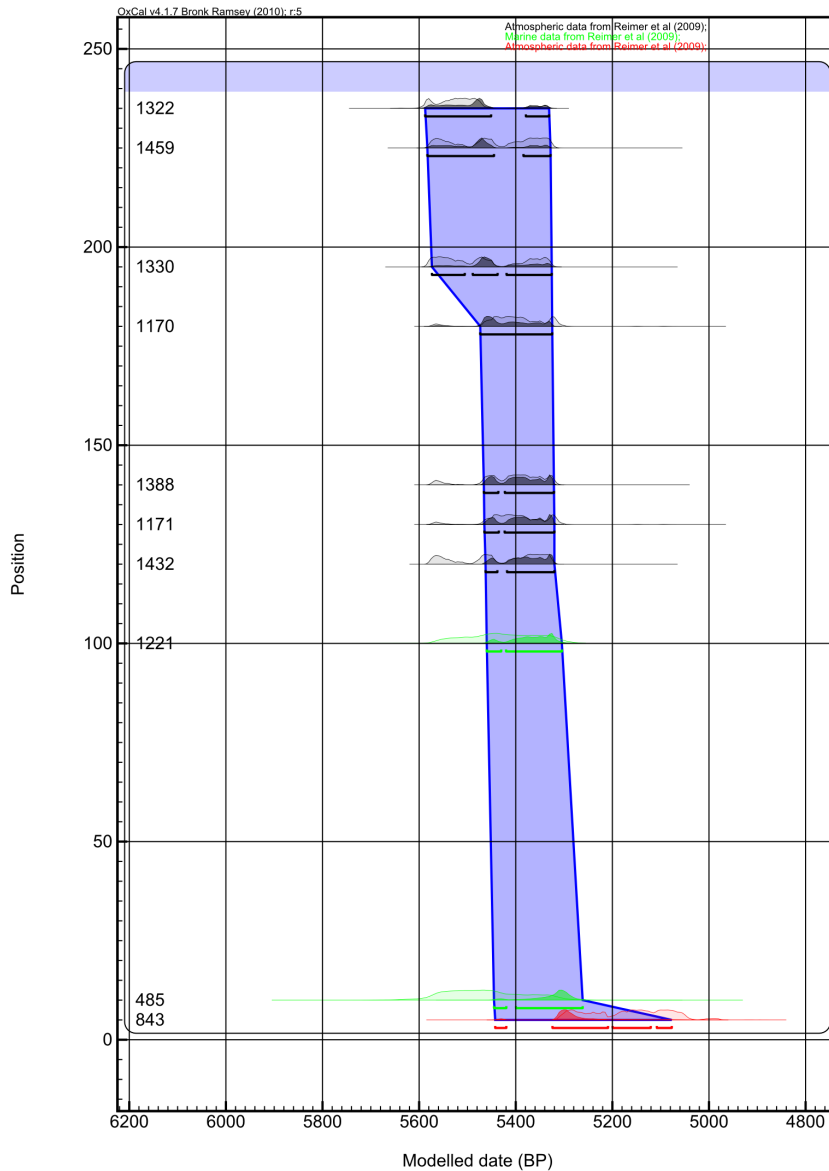


Figure 134: Deposition model for coastal sequence of JE0004 for P0.01 (Ramsey 2008).

As noted the models have resulted in the modification of a number of the radiocarbon dates, notably 1067, 1302 from the inland sequence, 1459, 1330, 1388, 1171 from the coastal sequence, and 1221, 485, 843, 1432 from both. Table 19 displays the adjusted ranges for each of these dates from each model.

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ADJUSTED DATES Sample no.	Calibrated Intercepts		Inland		Coastal	
	from	to	from	to	from	to
436	5581	5322	5583	5331		
1322	5597	5331			5588	5331
1459	5582	5321			5583	5328
1303	5593	5330	5580	5329		
1330	5585	5325			5574	5326
1302	5468	5075	5577	5326		
1170	5571	5306			5474	5325
1067	5642	5467	5574	5326		
1388C	5575	5315	5466	5321		
1388S	5569-5303					
1171	5571	5306			5465	5320
1218S	5580-5311					
1432C	5581	5321	5561	5317	5463	5320
1221	5565	5298	5477	5291	5460	5305
485	5595	5301	5455	5260	5445	5262
843	5310	5046	5442	5080	5443	5077

Table 19: Table of Radiocarbon ranges both un-modelled and adjusted for the two models.

The model shows that the base of both sequences (inland 12G and coastal 14-16G) have comparable rates of accumulation over a maximum of a 250 years (inland) c.5580-5330BP and 260 years (coastal) from c.5590-5330BP. This means they are virtually indistinguishable, especially when taking into account the variability in the statistics, which will result in slightly different outcomes each time the model is run for the same dates (Ramsey 2008).

The sample which joins both sequences (1432) has a tighter control on the coastal side (5463-5320BP or over 143 years) compared to the inland side (5561-5317BP or over 244 years) due to the closer spacing of the samples in this part of the section. Of the final three dates at the top of the sequence 1221 has the tightest control on the coastal model (5460-5305BP or over 143 years); the final two dates have comparable resolution in each model, with sample 843 ending the sequence with a broader degree of error but showing a probable younger date.

The two sequences show similar rates of accumulation (with the minor exception of sample 1432) through the mound. The close proximity of the dates, and error introduced by the plateau in the calibration curve have

resulted in the margin of error still exceeding 300 years in some parts of the model.

The most important aspect of this model is sample 485 which originates slightly after the change in accumulation from vertical to horizontal. The modelled date overlaps those of the vertical accumulation, whilst extending to a very slightly younger age. Although this does not suggest that the horizontal accumulation was part of a distinct and separate phase of shell mound accumulation, it does have a slight lean towards a younger age when compared to the dates above which all share a similar lower limit. However this is not conclusive enough evidence one way or the other and further successful dating of the inland site of the mound will be necessary to resolve this question, and the question of when the mound went out of use. The date from the burial is an isolated find, and although useful to show that the mound was used for a burial, does not inform on how this relates to the rest of the stratigraphy.

The model suggests that the mound accumulated over at least 328 years (5588 – 5260BP), but probably longer due to the fact that no dates were recovered from the terminal deposits of the site. This could be extended to 511 years if taking the burial into consideration. However the burial is not stratigraphically linked into the sequence and could be a later reuse of the site.

Section Summary

The deposition model informs on the formation processes of JE0004; it suggests that the site accumulated rapidly over c.300-500 years, but given the errors of radiocarbon dating it does not completely discount that the site could have accumulated in one season, however unlikely this may seem. However the second phase of accumulation has yet to be properly dated, meaning that this sequence could be extended. At present the results suggest a constant fast rate of deposition through the vertical phase of deposition, with no change in the rate of deposition

when deposition became horizontal. The determination of Delta R has made it possible for the model to work, and also raised questions about the use of modern Delta R values in archaeological research.

8.3.4 Fourth Stage: Dating a Range of Sites

Temporal extent of shellfish exploitation from test pit samples

The next stage in the dating process was to date a wider range of sites in order to determine the relationships between a broader number of sites and coastal processes.

The previous tests had shown that the AAR method was suitable for constructing a relative chronology between shell sites. However they had also shown the need for careful sample selection in order avoid contaminated samples or those exposed to heat from hearths. The test pitting methodology had been systematic, collecting samples from 25cm below the surface of a mound. This would mean that the thermal regime of the samples would have been comparable with the assumption that they had remained at constant depth since deposition.

A selection of samples from a variety of sites was chosen, meeting the criteria outlined in the methods (Figure 135 and Table 20). In addition several samples from unusual contexts were also chosen for comparative purposes.

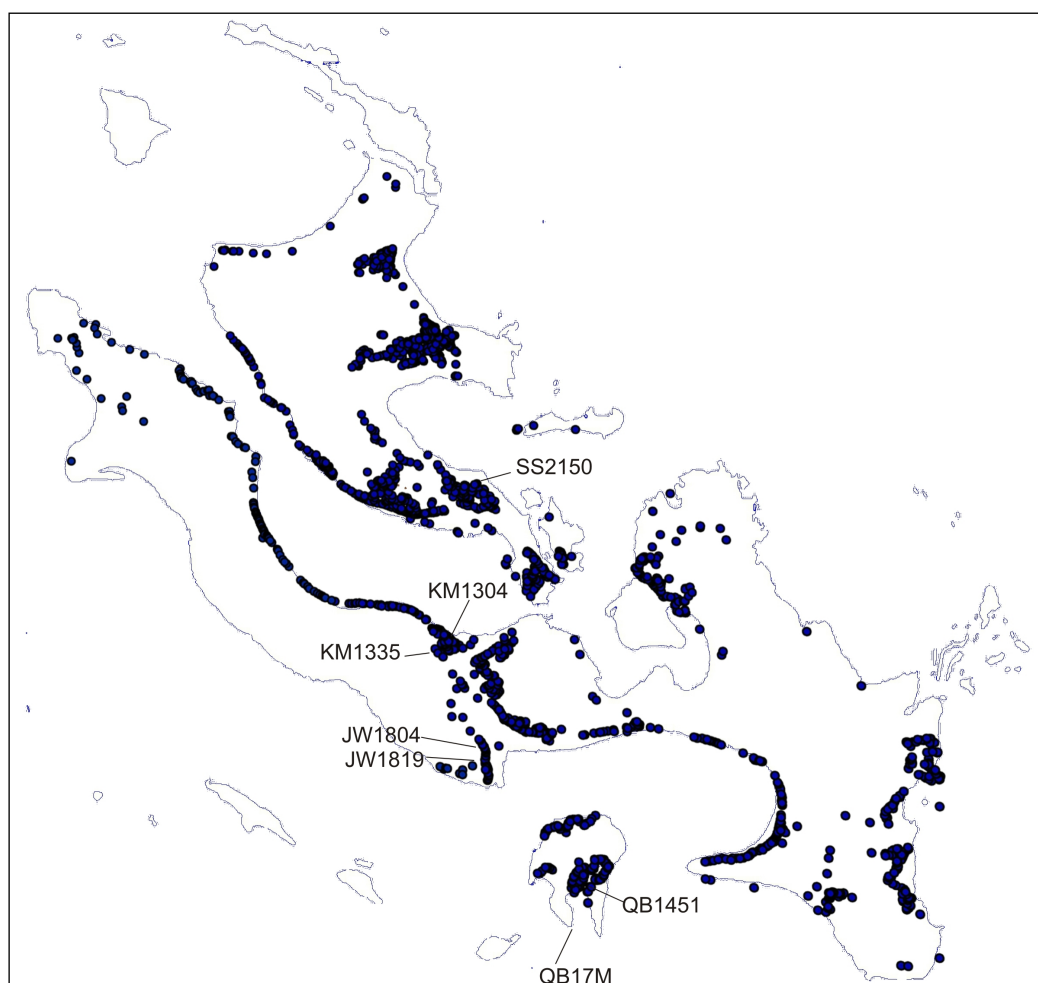


Figure 135: Location of AAR dating program samples from test pits.

Site	Site Type	Context type	Depth
JW1804	Shell Mound	Shell	25cm
JW1819	Shell Mound	Shell	25cm
KM1304	Shell Mound	Shell	25cm
KM1335	Shell Mound	Shell	25cm
SS2150	Shell Mound	Shell	25cm
QB1451	Shell Scatter	Shell	0-5cm
QB17M	Underwater Cave	Shell/Coral	70cm

Table 20: Table showing sample depth, type of site and composition of context.

The two samples from unusual contexts both came from Qumah Bay. The first (QB17M) came from a site which had been excavated by the diving team at 17m depth, and recovered from deposits under a submerged cliff of c.1.5m height. The cliff was undercut, and deposits had accumulated around the base. The second was from a scatter on a cliff top overlooking Qumah Bay. Both contexts offered unknowns; such as the effects of water on the shell, or the effects of insolation. The

difference in water temperature from air temperature and the buffering of the deposit on temperature are unknowns. *S. fasciatus* is a shallow subtidal grazer, therefore to find it at 17m depth suggests that it has either been carried from shallower water by currents, or it is much older, being associated with a period when the sea level was lower and closer to the cliff under which the samples were recovered.

The scatter offers a different set of problems; would it have originated from one depositional event or would it be an amalgamation of several over time? Was the deposit of anthropogenic origin? Large birds of prey are known to feed on shellfish and could in theory create a shell scatter; large bird of prey nesting sites were observed, composed of sticks with material such as gazelle bone and shell strewn about. The thermal heating from the sun is another unknown factor; with the shells exposed to the elements the thermal regime that the shells experience has high diurnal and seasonal temperature variation.

The following graphs show the results for the selected sites results show a degree of variation between the sites, shown in Figure 136.

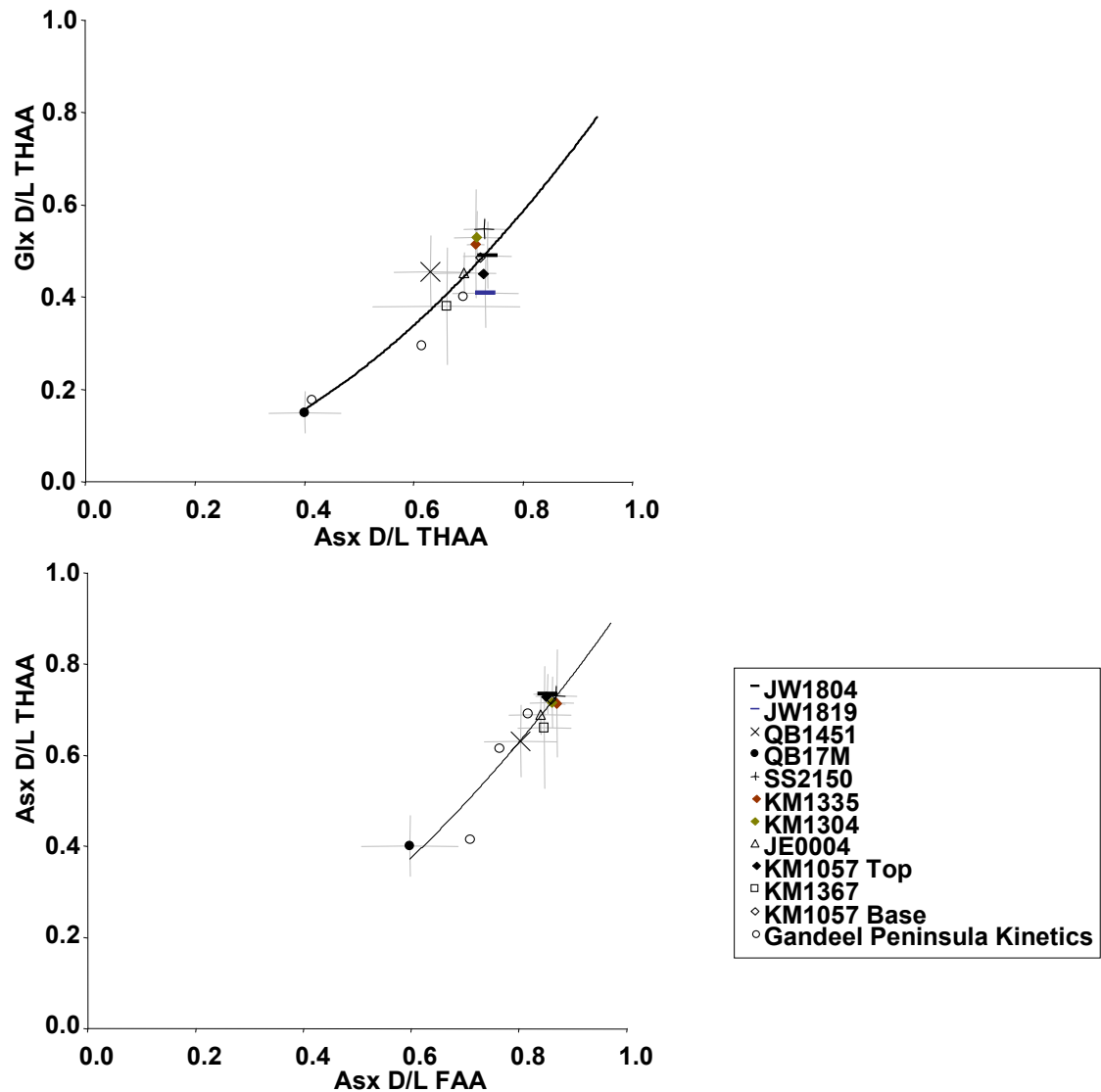


Figure 136: Upper – Asx and Glx D/L THAA for test pit AAR samples plotted against Gandeel Peninsula Kinetics (Demarchi *et al.* 2010); lower – The same but with Asx D/L THAA and FAA plotted. Error bars are to two standard deviations.

The Asx D/L FAA/THAA results of the experiments suggest that samples selected from secure contexts are all of a similar age. This is also reflected in the Glx/Asx D/L THAA plots, with the exception of JW1819 which shows some variation from the others. This strongly suggests that these shell mounds accumulated as part of the same phase of intensive shellfish exploitation (perhaps with the exception of JW1819). The sample from QB17M suggests a much younger thermal age, whilst the scatter QB1451 is indicative of a slightly younger thermal age than the other sites, despite the postulated greater exposure to solar insolation.

The results of this experiment show that the context of the samples is influential on the results (rates of racemization) and that selecting suitable samples for dating is crucial. Using the technique it has been possible to show that the majority of sites tested are from the same phase of shell mound building activity. Where these sites are associated with palaeoshorelines it allows a tentative date to be assigned not only to the palaeoshoreline but also to the sites associated with them.

Using regression derived from AAR samples paired with radiocarbon dates (Figure 137) it is possible to assign dates to those AAR samples not paired with radiocarbon dates and derived from test pits. These have large errors, a reflection of the cumulative error of the AAR and radiocarbon analyses exceeding 500 years; however the dates are a useful indicator (Table 21).

8. Temporal Relationships

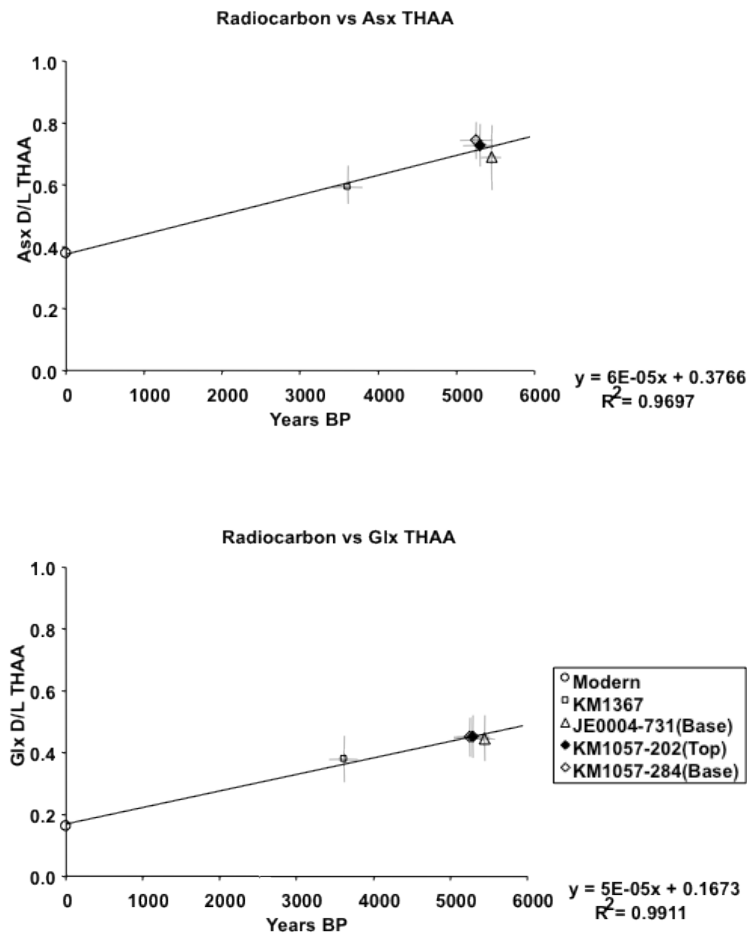


Figure 137: Graph plotting paired AAR Radiocarbon samples for Asx THAA (left) and Glx THAA (right). Equations used in regression are shown bottom right with associated R^2 values.

Site	THAA Asx Value	Regression Age
QB17M	0.400976434	335
Bea Kinetic T=0	0.415074723	570
QB1451	0.52383356	2382
KM1335	0.712006802	5518
KM1303	0.715526041	5577
SS2150	0.729631476	5812
JW1816	0.730724682	5830
JW1804	0.734760387	5898

Table 21: Table of dates calculated by regression.

The table shows some very interesting trends with the two sites from the Khur Maadi having similar dates to the excavated site of KM1057. The sites from Southern Saqid and Janaba West appear to come from an earlier phase of activity, although these dates are still within the margin of error for this technique and could be contemporaneous with the KM sites. Unsurprisingly the two Qumah dates are not associated with the other

main phase of shell mound building activity, although whether this is real or an artefact of taphonomic processes is unclear. It certainly highlights the need for further testing of the AAR method. The final point of note is the Gandeel Peninsula kinetics sample; this is the unheated sample and gives a much younger date than the other samples. This is highly unexpected given the location of the Gandeel Peninsula sites on extensive palaeoshorelines. These had been expected to be contemporaneous with the other dated palaeoshorelines on the island. This date highlights the need for further dating to test whether this date is evidence for reuse of the site, or is a true representation of shellfish gathering in this area.

Section Summary

This section has successfully shown the potential of the AAR method to help address the question of the temporal extent and spatial variations in shellfish exploitation. The KM sites correlate well with the dates already obtained, although the data suggests that the JW sites formed as part of a slightly earlier phase of shellfish exploitation (or it is possible that the JW samples were exposed for longer before burial, or were exposed to heat from burning). This is strange given that the two groups of sites are located along the same palaeochannel. There are a number of possible explanations such as sampling bias or that the dates fall well within the range of the error. The sites of the two areas are markedly different; KM being dominated by low mounds, JW by large mounds and these dates may be a true reflection of this. The same can be said for the Southern Saqid date, although this sample came from a low mound.

The Gandeel Peninsula date is problematic, but given the evidence for palaeoshoreline formation it is likely that this represents reuse of the mound. Further research is needed to clarify this.

The youngest dates from Qumah highlight the need for further research; indeed the samples were chosen in order to test the versatility of the

method. Ideally these samples would also be processed with paired radiocarbon dates to shed light on these question, unfortunately the budget did not stretch this far. The next section will aim to address variability in the samples and determine whether archaeological heating of a shell can affect results and be detected where it does.

8.3.5 Fifth Stage: Constraining the AAR Method and Quantifying Archaeological Heating of Shell

This section has two aims which are interlinked. The first is to determine whether the AAR method can be more tightly constrained, by building upon and extending the kinetics work undertaken by Demarchi *et al.* (2010). The second aim follows on from this by trying to detect archaeological heating of the shell by a second heating experiment at higher temperature than the kinetics test. Detecting archaeological heating of shell is important as it will allow a greater understanding of the processing procedures used in shellfish preparation. This contributes to the overall thesis aim of investigating social and economic activities at coastal sites.

Kinetics Test

The kinetics experiments conducted by Demarchi (Demarchi *et al.* 2010) provided an excellent guide for the subsequent testing of the method of archaeological sites. The samples used in this original experiment were collected in 2006 as part of the initial reconnaissance of the islands. The *S. fasciatus* samples are known to come from a site on the Gandeel Peninsula, however other than this their provenance is unknown. For example it is not known whether they originate from surface samples, or samples from test pits. Further to this when the results of the kinetics test are viewed against the results presented here it becomes apparent that the samples used in the kinetics tests are much younger than those of known archaeological provenance. Indeed they are even younger than

the geoarchaeological samples from KM1367, but older than the modern samples used in these experiments.

The decision was therefore taken to undertake a new kinetics test using modern samples collected live from the water in 2009 at the base of the cliff in front of JE0004. Because of the uncertainty of the effects of heating by fire on the shells, the opportunity was also taken to run a series of heating experiments on modern samples, paralleling the new kinetics tests.

The kinetics experiments follow the same protocol as those of Demarchi (Demarchi *et al.* 2010), with samples heated to a temperature of 140°C to initiate racemization. Time points of 0, 1, 2, 4, 6, 8, 24, and 48 hours were used, with two samples processed per point (Figure 138).

8. Temporal Relationships

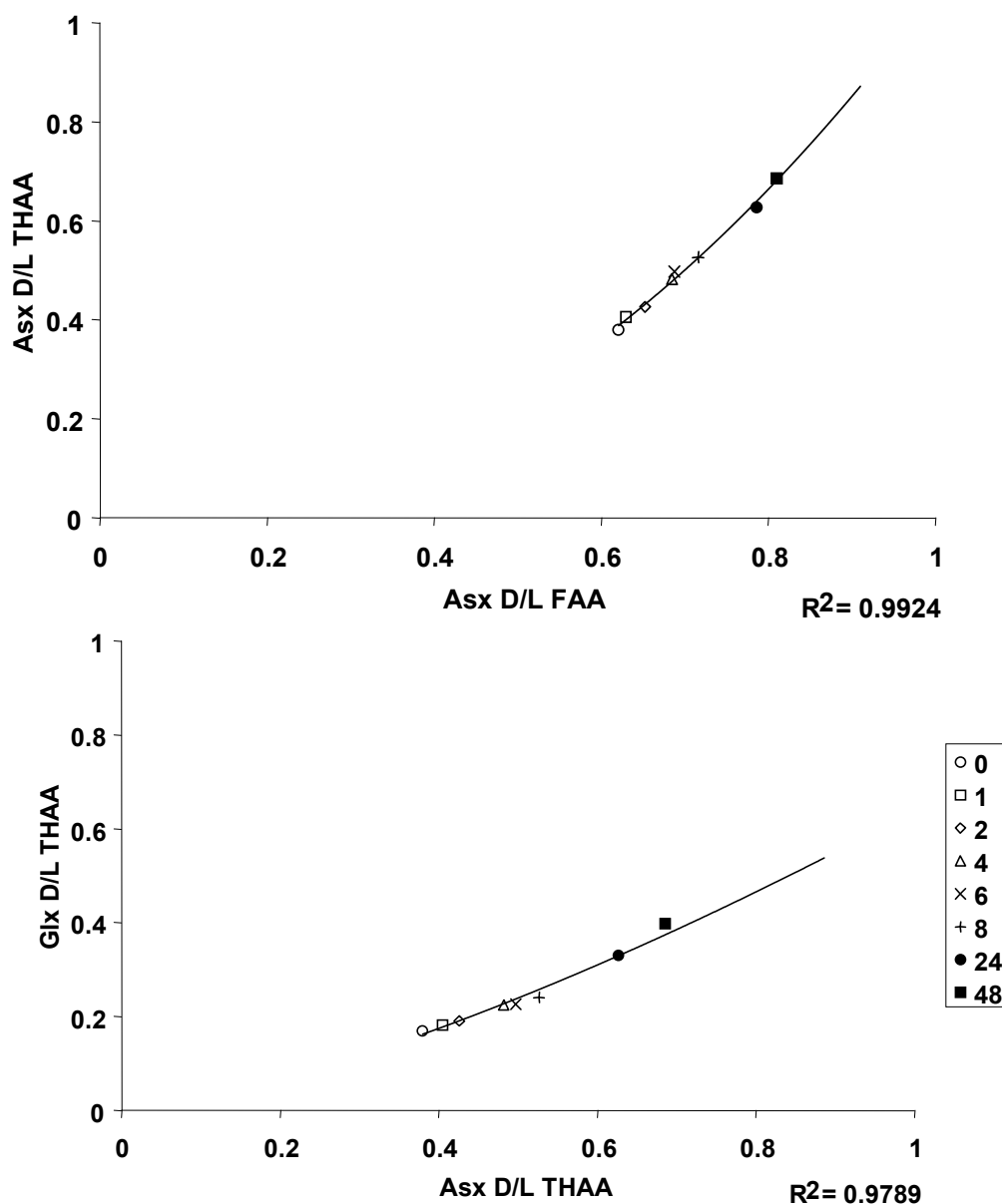


Figure 138: Kinetics test; upper is Asx D/L FAA against THAA; lower is Asx D/L THAA against Glx D/L THAA.

The experiments show a linear relationship between time and racemization, as would be expected for constant temperature where time was the only variable.

The two kinetics tests make for a good comparison (Figure 139), with both lining up well. These clearly show that although the samples in the original kinetics test are much younger than the archaeological samples tested, they are older than the modern samples tested in this kinetics experiment.

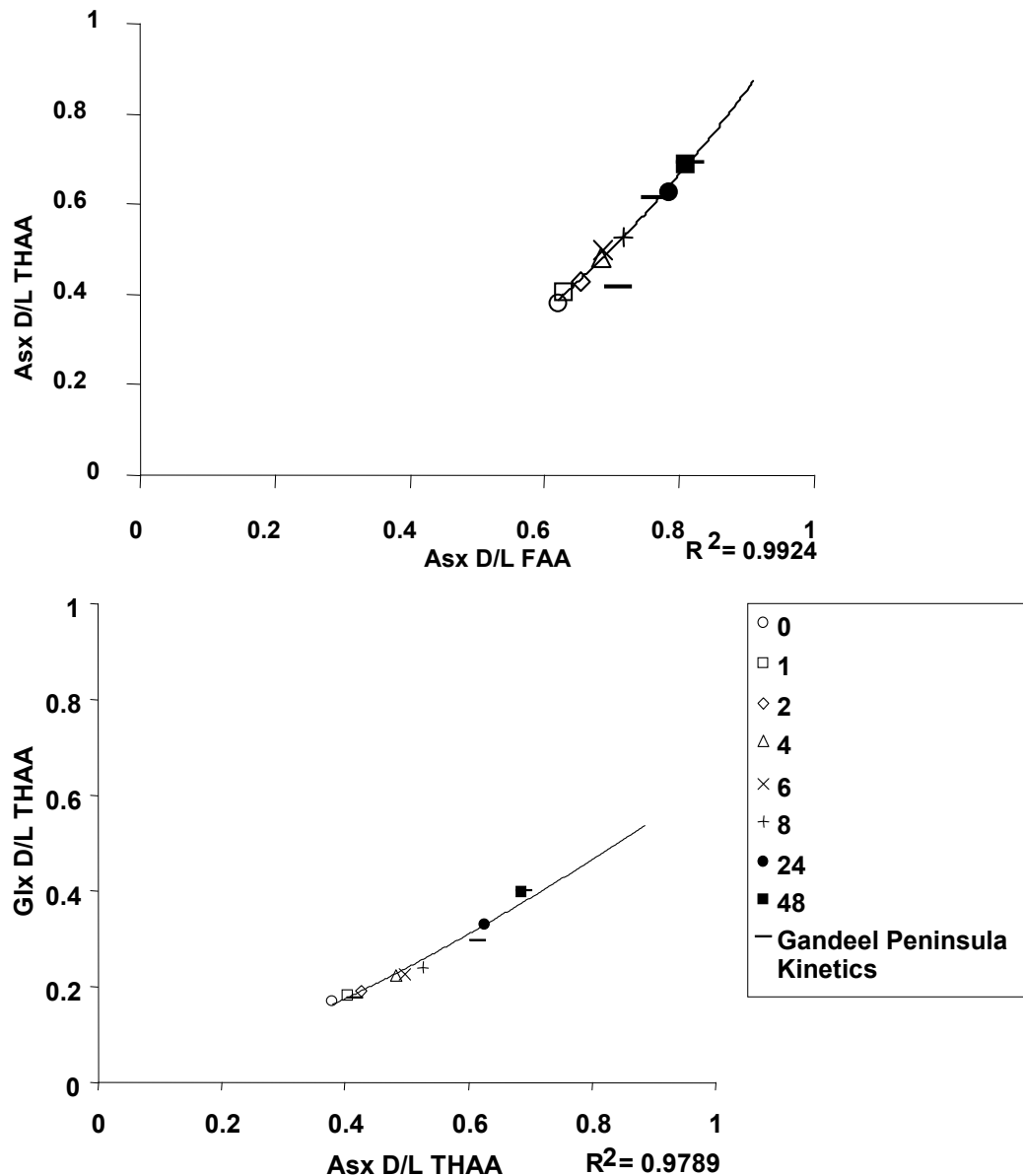


Figure 139: The two kinetics experiments plotted against each other. The Gandeel Peninsula Kinetics (Demarchi *et al.* 2010) show a good agreement for Asx D/L THAA against Glx D/L THAA (upper R^2 value is this experiment, lower is for Gandeel Peninsula).

The Kinetics experiments tie in well with the data already collected, and those already carried out by Demarchi (Demarchi *et al.* 2010). This sets a natural point on which to measure archaeological samples; those whose data points fall away from this line are likely to have had their closed system compromised and can therefore be discounted (eg Penkman *et al.* 2011).

Heating Experiment

The heating experiment was an attempt to determine whether archaeological heating of a shell could be detected through AAR analysis. The hope was that short intense episodes heating, either through deliberate cooking of the shellfish or by discarded shellfish remains being close to hearths, would affect the amino-acid composition in a way which could be detected through analysis.

The experiment would be run in a similar manner to the kinetics experiments, except the temperature would be 280°C, and the time points would be 0, 5, 15, 30, 45 and 60 minutes (Figure 140). It was hoped that this would emulate the short sharp bursts of heat experienced in campfires when cooking shellfish. The temperature of 280°C was chosen after having reviewed what literature there was on this topic. One paper on cooking and AAR was found (Brooks *et al.* 1991), however a number of papers were found on the temperature of camp fires (eg Brain and Sillen 1988).

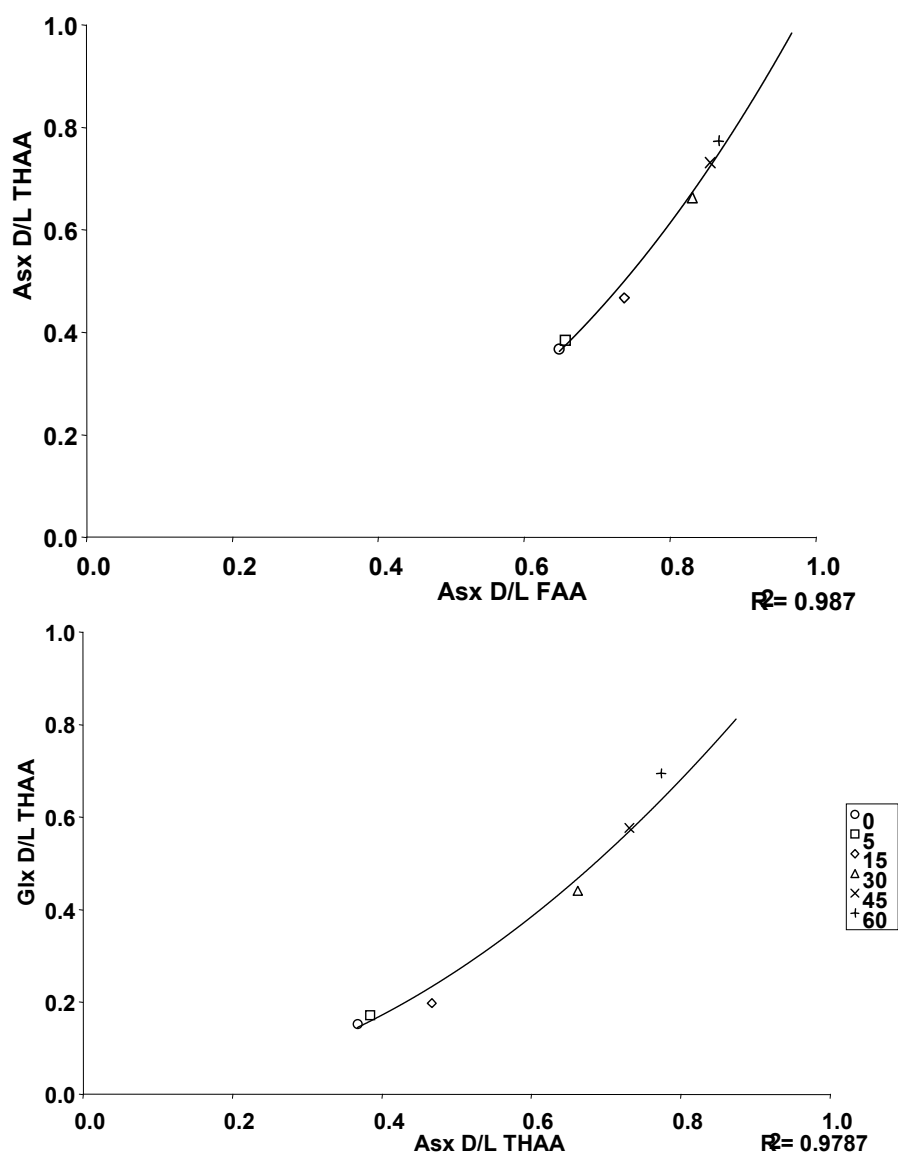


Figure 140: Heating experiment, left is THAA Asx D/L against THAA Glx D/L; right is FAA/THAA Asx D/L.

The experiment showed an increased rate of racemization over the kinetics tests, as would be expected for a higher temperature environment. Thirty minutes of heating at 280°C resulted in more racemization than 140°C for forty-eight hours; with the final reading for the heating experiment well exceeding the kinetics experiment. It was this accelerated rate of racemization that was hoped would leave a tell tale indicator within the amino-acids.

Previous studies have shown there to be variation between unheated and heated samples, relating to variations in the D/L values between the two

data sets. In particular this relates to concentrations of aspartic acid, serine and arginine (Brooks *et al.* 1991; Demarchi *et al.* 2010). The authors state that it should be possible to recognise exposure of the sample to high temperatures by analysis of THAA Glx D/L vs THAA Asx D/L values (Figure 141).

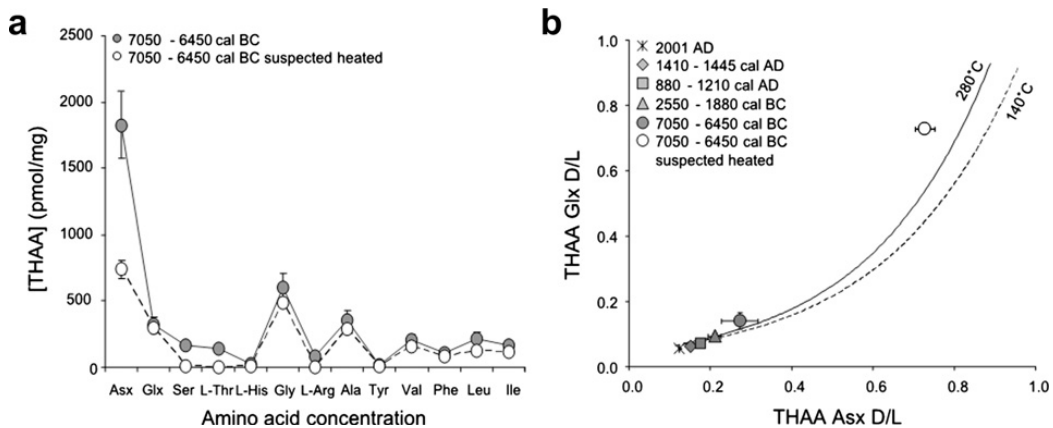


Figure 141: Demarchi *et al.* 2010 heating detected.

The heating and kinetics experiments have can be plotted against one another (Figure 142) to test the hypothesis put forward by Demarchi *et al.* (2010) (Figure 141). The Asx THAA D/L versus Glx THAA D/L plot from the Kinetics and Heating experiments of this study support the findings of Demarchi *et al.* (2010), and show a divergence between the lower temperature (140°C) of the kinetics experiments over a longer period, and the higher temperature (280°C) of the heating experiment over a shorter period.

8. Temporal Relationships

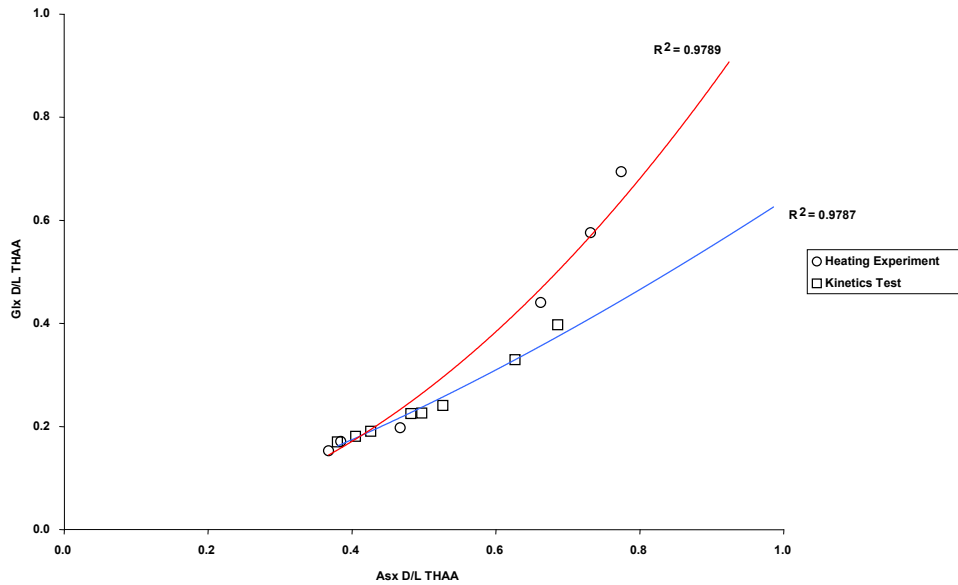


Figure 142: A heating signal? Asx THAA D/L plotted against Glx THAA D/L for the kinetics experiment (140°C over 48 hours) and heating experiment (280°C over 1 hour). Upper R^2 value is for the heating experiment, lower for the kinetics test.

These two tests can be used to assess the integrity of the closed system of a sample, with any point falling away from these lines being compromised. Compromised samples can be taken out of the data set since they do not behave in a linear manner. Samples closest to the kinetics test trajectory are likely to be unheated, whilst those closer to the heating test trajectory are likely to have experienced archaeological heating. Figure 143 shows all data points collected as part of this thesis plotted against the kinetics and heating test trajectories.

8. Temporal Relationships

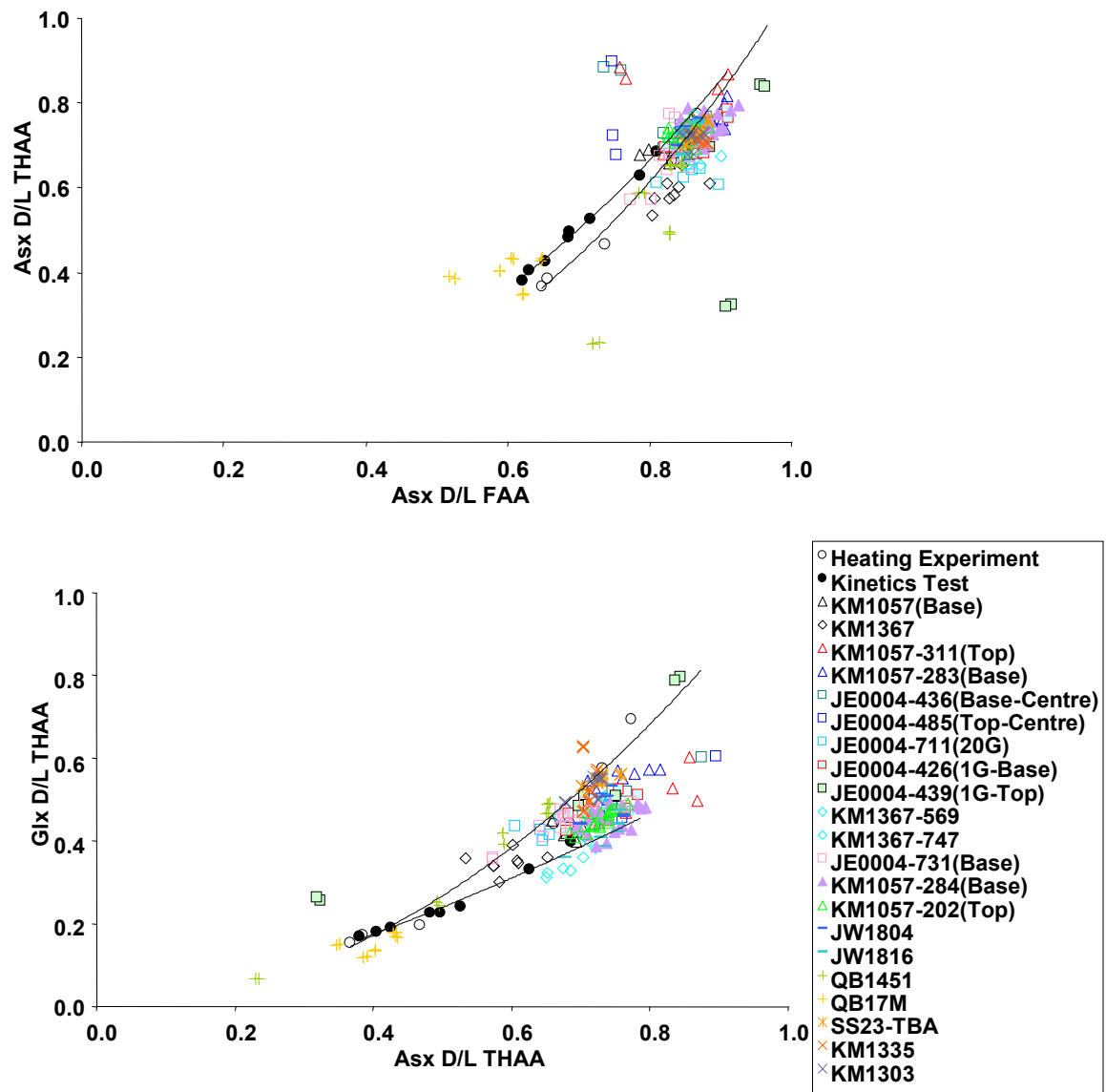


Figure 143: All AAR data points plotted against kinetics and heating test trajectories. For Glx against Asx points falling closer to the heating line are likely to have been archaeologically heated. Those falling away from both lines have had their closed system compromised and must therefore be discounted from the results.

The above graph shows that the majority of samples have experienced some degree of archaeological heating. This is most likely consistent with the shells having been heated during meat extraction. It is also possible that in some cases shells were deposited in or close to active hearths or that later hearths were created over the deposits heating the shells post-deposition. The graph even suggests that some replicates from KM1367 have been heated raising the possibility that they are reworked (washed in from the shell mounds) rather than part of the death assemblage.

With the exception of the Qumah samples (and one replicate from KM1335) all of the test pit samples fall between the two trajectories and are therefore from closed systems.

Section Summary

The Stage 5 dating tests have demonstrated that it is possible to detect archaeological heating in shell. The majority of samples tested had experienced some degree of archaeological heating, allowing an assessment of some of the social and economic processes of the shellfish gatherers.

8.4 Chapter Summary

This chapter is instrumental in tying together the information presented in the previous chapters. Dating allows sites and samples with no stratigraphic connections to be associated.

This chapter has allowed a quantification of prehistoric shellfish exploitation through dating techniques. The rangefinder dates initially showed that exploitation was sufficiently intense to accumulate shell mounds with c.300-500 years of activity. The high resolution dating program focused on determining the rate at which shell mound formation processes occur. A key question is whether shell sites on the islands represent an intensification of shellfish exploitation or whether they are the result of a longer gradual build up of material over a longer period. The rangefinder and high resolution dating program have shown that shell mound accumulation of the two dated sites was rapid and intense. Dating samples from the test pits has shown that these sites originated either just before or during this period, suggesting that the sites of the Farasan Islands are the result of a burst of intensive shellfish exploitation.

It has also hinted that there may have been more than one phase of shellfish exploitation, raising the possibility that different coastlines were

exploited at different times, but that phases of exploitation closely followed each other. The few dates recovered so far suggest that Janaba West has the oldest phase of exploitation, possibly associated with that at Southern Saqid. Janaba East is next closely followed by the Khur Maadi. Further dating is needed to substantiate this. It is possible that the uplift and geomorphological change around the islands did not happen at the same time, with shellfish exploitation taking advantage of windows of ecological productivity as they occurred along different stretches of coastline. The KM geoarchaeological date suggests that productive shell beds were present long after the cessation of shell mound building at KM1057, however the period in between this is not represented and it may be that conditions were in constant flux.

In terms of social and economic activity this chapter has shown that shellfish were routinely heated, probably as part of the processing procedure. Although no patterns in heating have been detected it may well be possible that *S. fasciatus* was smashed at some sites rather than heated to extract the meat. KM1057 stands out as it has very little evidence for hearths, therefore means of heating the shells. However the majority of samples showed evidence of heating. The final task for investigating social and economic activities is to apply the dating evidence from this chapter to the scale of material processed in order to quantify these activities.

In addition this thesis has contributed a new local Delta R for this archaeological period and questioned the use of modern values for archaeological samples. It has also tested and proved the use of AAR in hotter climates. Despite not reaching the resolution hoped for, the method proved a cheaper alternative to radiocarbon dating for determining the relative chronology between shell mound sites, and offered the possibility to infer calendar dates by regression. Despite the obvious cost in terms of time for this thesis, the successful application of AAR in the region paves the way for future research, and an alternate to radiocarbon dating especially at shell midden sites.

Chapter 9

Quantifying Social and Economic Activities

9.1 Introduction

One of the key questions this thesis set out to answer is what social and economic activities were associated with the prehistoric coastal sites on the Farasan Islands. The survey and excavation chapters have both contributed evidence towards this objective, including site distributions, size of sites and composition of sites. The previous chapter offered models for both the timing of site accumulation and deposition. This data can be combined to calculate estimates for the number of people involved in shellfish gathering, and the time they would have spent at each site. Although these data are built on a number of assumptions and have wide ranges they are useful because they offer explanations based on data which would otherwise be unavailable. Comparisons can be made to sites where more data is available drawing out similarities, differences, or even informing on the reinterpretation of this data. Further research will no doubt supersede these models as more data becomes available.

9.2 Method

The literature review has already reviewed ethnographic data relating to the gathering of shellfish, in particular the study by Meehan (1977) which documented in detail shellfish gathering during a dry season when other sources of food were scarce. Shellfish gathering was quantified, with values broken down by age group, sex, and ability; in addition the nutrition derived from the harvest was also documented. Data such as this gives the opportunity to extrapolate shellfish gathering potential and contribution to the diet. However this is based on the assumption that the environmental conditions are comparable, as well as social and economic factors. These are summarised here:

- Ease of gathering
 - The environments offer a similar range of challenges for gathering shellfish (mud vs sand/coral)

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- Target species occur in similar densities
- Similar distances are travelled to reach the shell beds
- Other food resources are comparable (terrestrial or marine)
 - Ease of gathering
 - Contribution to diet
- Influence of social taboos is negligible
- Shellfish are used exclusively for food, and are prepared and eaten immediately following harvest (and not processed for storage/used as fish bait)

The impact of these assumptions needs further research; however this is not in the scope of this project. That they exist must be acknowledged, and the limitations of making them taken into account when viewing the results.

From the measurements of the sites carried out in the survey it has been possible to estimate the volume of each measured shell mound. The average of these values has been extrapolated to estimate the total volume of all of the sites on the islands. The test pits and excavations have allowed an assessment of the composition of shell sites, and the density of shell. Finally the dating has provided a framework for the time depth of shell mound accumulation on the islands.

The excavated sites provide the opportunity to calculate the amount of shell in each layer of the site, and the volume of the site. These can be used to estimate how many shellfish are represented in any one layer, and therefore any one depositional event (providing that each layer was deposited as one abrupt event, rather than a series of discreet ones). Using this data and data on the amount of shellfish meat each live

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shellfish will yield, it is possible to calculate the nutritional value in each event – and also cumulatively for the entire midden. Based on Meehan's (1977) data on the contribution of shellfish to diet, it is possible to calculate how long it would have taken to gather the shellfish in the layer, and the nutritional value it represents. Therefore the number of people sustained by either the layer or the shell mound as a whole can be calculated. Finally using the deposition model and radiocarbon dates it is possible to generate a number of scenarios for how many people used the shell mound and for how long.

Assuming that the variation between different shell mound groups is insignificant, both in terms of size, volume and composition, then this data can be extrapolated across the island. This provides scenarios for how many people the shell mounds could have supported. Making yet more assumptions it is possible to create scenarios which inform as to whether the population on the islands would have been seasonal visitors or not.

The positive side of these calculations are that they provide models for the social and economic activities for the fisher-gatherers. The main drawback is the number of assumptions involved in the calculations.

9.3 JE0004

The excavation of JE0004 has allowed an assessment of the volume of each excavated layer and extrapolation through to unexcavated areas. The total volume of excavated material is 12.6m^3 , or 5.5% of the total site, with 2.6m^3 of material left to excavate to expose the full section to bedrock.

Each layer has been modelled as a truncated cone, where activity is concentrated at the centre of the layer with material thinning towards the edges – in line with field observations. Although this is an overly simplistic model for a number of the layers, the cumulative volume for the entire mound based on the calculations for each individual layer (228.5m^3) is

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comparable to that calculated from the survey of the external dimensions of the site (275m³).

Using the main species constituents and extrapolating from the excavated material the mound contains (Table 22):

	<i>S. fasciatus</i>	<i>C. ramosus/P. trapezium</i>	<i>C. reflexa/S. marisrubri</i>	<i>P. nigra</i>
Volume (m ³)	67.2	88.5	11.7	20.7
Weight (using 1000kg/m ³)	67200	88500	11700	20700
Meat per shell (if 10% weight of shell is meat; kg)	7400	9700	1300	2300

Table 22: Calculations for species composition of JE0004.

The average density of the material has been calculated at 1000kg/m³ from field observations. The total weight of shellfish meat has been calculated using the estimation of a 10% meat to weight ratio; this figure was derived from field observations for *S. fasciatus*; unfortunately no work has been undertaken on *C. ramosus/P. trapezium*, *C. reflexa/S. marisrubri* or *P. nigra*. No estimates for these species exist in the literature and this must be a priority for future field work.

Meehan's (1977) study gives an average of 0.6kg of flesh consumed a day, as part of a mixed diet consisting of 0.5kg (European) carbohydrates and 0.4kg vegetables, with an average person gathering 2.4kg of shellfish flesh a day. However she also states that 2.4kg of flesh would provide enough calories to sustain a person for a day, which although unlikely gives an upper limit for the amount of shellfish consumed by a single person. Either the fisher gatherers of the Farasan Islands ate a varied diet whereby some gathered shellfish, some fished or hunted, and others gathered plants, or they subsisted predominantly on shellfish. The evidence from excavated sites suggests that fish played an important part in diet, with the presence of seeds raising the possibility of wild plant processing.

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These figures can be used to estimate ranges for the number of days per year which the site was occupied – or in which shell accumulation occurred since other activities may not result in shell accumulation (Table 23). This uses the data above and the deposition model for the time depth of the site which is 328 years (without the burial) and 511 (taking the burial as the terminal activity at the site).

				Days/year (1 person)		Days/year (5 people)		Days/year (10 people)	
				328 years	511 years	328 years	511 years	328 years	511 years
JE0004	Flesh per day (kg)	Days	Years						
Shellfish diet	2.4	8620	23.6	26	17	5	3	3	2
Mixed diet	0.6	34480	94.5	105	67	21	13	11	7
Total Meat (kg)	20700								

Table 23: Duration of site occupation based on amount of shellfish flesh at site.

This shows that a site such as JE0004 could have been occupied for as little as two days a year during accumulation. However there are many variables which have not been taken into account, not least the presence of smaller peripheral sites which could have been used for shellfish processing before bringing meat back to the site – or they may well have been sites in their own right.

9.4 KM1057

Site KM1057 accumulated between 5461-5079BP over a maximum of 382 years. This site has a significantly different composition to JE0004, with notably lower concentrations of sediment, and is significantly larger.

Calculations were conducted in the same manner as for JE0004 and are presented in Table 24. Briefly this involved calculating the weight of shell, and then estimating the meat yield from these. Different diets would result in different amounts of shellfish flesh consumed (either 2.4kg a day for a short period or a more sustainable 0.6kg per day). This is then divided up into the number of days a year that the site could support a population.

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KM1057	Flesh per day (kg)	Days	Years	Days/year (1 person)	Days/year (5 people)	Days/year (10 people)
Shellfish diet	2.4	37600	103	98	20	10
Mixed diet	0.6	150300	412	394	79	39
Total Meat (kg)	90200					

Table 24: Duration of site occupation based on amount of shellfish meat at site.

9.5 All Sites

The same calculations were applied to the surveyed sites and produced the following results (Table 25) but this time producing figures for how many people could be sustained per day over a 300 or 600 year period. As can be seen there is a high degree of variation between research areas. These show that the 476 sites surveyed would provide enough nutrition to support anywhere between 29 and 234 people a day for the date ranges established for KM1057 and JE0004.

Area	No. sites	Tot. vol. (m ³)	Tot. Weight (kg)	Tot. Meat Weight (kg)	Food/day 300 years		Food/day 600 years	
					2.4kg /day	0.6kg /day	2.4kg /day	0.6kg /day
KM	82	19,151	19,150,572	2,106,563	8	32	4	16
SS	167	78,764	78,764,008	8,664,041	33	132	16	66
QI	55	18,717	18,716,971	2,058,867	8	31	4	16
QB	21	3,020	3,019,893	332,188	1	5	1	3
JW	151	19,923	19,923,322	2,191,565	8	33	4	17
Totals	476	139,575	139,574,767	15,353,224	58	234	29	117
Average	-	27,915	27,914,953	3,070,645	12	47	6	23

Table 25: Calculations for amount of nutritional value from surveyed sites.

Extrapolating the averages is risky due to the variation between the sizes of site in each research area. Therefore in addition to using the average values, the minimum and maximum have also been used (Table 26).

9. Quantifying Social and Economic Activities

	Tot. vol. (m ³)	Tot. Weight (kg)	Tot. Meat Weight (kg)	Food/day 300 years		Food/day 600 years	
				(2.4kg)	(0.6kg)	(2.4kg)	(0.6kg)
Average	742,104	742,801,128	81,708,124	311	1,244	155	622
Lowest Average	371,052	370,891,773	40,798,095	155	621	78	310
Highest Average	1,326,792	1,325,782,851	145,836,114	555	2,220	277	1,110

Table 26: Calculations for amount of nutritional value in all sites using averages.

The average values suggest that the islands could have been supporting between 78 and 2200 people everyday for the established date ranges. The degree to which these date ranges are representative is debateable; however until further research they can provide a useful assessment.

9.6 Chapter Summary

These figures are built on a number of assumptions, not least that all the shellfish was eaten rather than used for some other purpose (eg storage, bait dye). The extrapolated figures suggest that the volume of shell could support a population of at least 78 year round, however this assumes that all of the un-surveyed sites conform with the surveyed sites, which they might not. Likewise further dating may show a more extended period of shellfish exploitation or even multi phase site creation. Although the overall figures do not help with the question of seasonality the two excavated sites suggest that they could not support a single person for the entire time depth of the site. Therefore the sites must have been repeatedly visited over longer time scales as permanent places in the landscape. Whether this was part of a systematic exploitation of the coastline, or seasonal movements is unclear.

Chapter 10

Discussion

10.1 Introduction

The discussion is presented in five sections; after this brief introduction the two research questions will be addressed, first the question of intensification followed by the emergence of large shell mounds. The social and economic activities of the prehistoric fisher-gatherers and their responses to change have been allocated a separate section, utilising results from the previous two sections. The final section will quantify the impact of this research. Each section is broken down into a number of subsections dealing with a specific area of research.

10.2 Intensification

The question of intensification versus continuous exploitation is key to this thesis. At its core is the discrepancy between sites on the mainland which are more dispersed, often smaller, and in small groups, compared to those on the Farasans which are often large and densely packed. In both areas sites are predominantly located along palaeoshorelines, and stone tools of similar typologies have also been found. Apart from dating to the same period these are the only similarities between the two areas.

The 2811 sites of the Farasan Islands demonstrate a marked intensification of shellfish exploitation in the region; however this is not mirrored on the mainland. The dating of the two excavated sites suggests that they were the product of intensive shellfish gathering over relatively short periods. However as has already been alluded to large shell mounds often dominate groups of smaller sites, and in other locations the large shell mounds have been shown to be younger than the smaller sites (eg Bailey 1994). Therefore the smaller sites may be older and more representative of a longer period of exploitation at a lower rate of accumulation than the larger mounds. Countering this argument is the dating from the test pits, which suggest that the majority of sites accumulated during a relatively short period. Likewise the association of

groups of shell sites with palaeoshorelines adds a constraint to both their initiation and abandonment.

The evidence suggests that shellfish exploitation on the islands was an intensive burst of activity. The test pits dates potentially complicate the story by suggesting that different groups of sites were active at slightly different times. This could be a manifestation of social and economic responses to local geomorphological change, induced by tectonics. If the islands were in constant flux, or punctuated equilibrium, fisher-gatherers would have exploited ecological habitat patches as they arose. They would focus intensively on one area until changing conditions decreased the productivity of the shell bed, whilst in another area conditions would become favourable and productivity increase. Exploitation would then change focus to take advantage of the new area. Further testing is necessary; however on current evidence this seems plausible.

Although not all dates support this, notably from the Gandeel Peninsula and Qumah, it is likely that these dates are erroneous and can be discounted. Further research is necessary to better understand these groups of shell mounds.

The distribution of sites is not the only line of evidence supporting intensive shellfish exploitation; the data gathered on the size and volumes of shell is also persuasive. Although they suggest that a population could have subsisted on nothing more than shellfish year round on the islands, this is a very unlikely scenario, not least because of the chance of protein poisoning. The sites on the Dhalak Islands have surprisingly similar spectral signatures to those on the Farasan Islands, suggesting that very similar activities were taking place on the other side of the Red Sea. The Farasan sites are typologically linked to the mainland through lithics; however no one has examined the Dhalak sites to see when they date to or who they are typologically closest to. It is possible that the Farasan fisher-gatherers had become removed from mainland populations and had engaged in migratory intensive coastal exploitation. Research by

Khalidi (2009) suggests a tentative link between obsidian sources on both sides of the Red Sea, but further research is needed to clarify this.

Although the mainland Tihama sites occur during the same period, they are different in terms of composition (both lithics and faunal) and shellfish species exploited (eg Beyin 2010). Although a relationship cannot be ruled out, the differences suggest that these sites may be the product of two independent groups of fisher-gatherers.

A key question is what initiated this period of intensive exploitation and why did it stop? These themes have already been explored in the regional context in the literature review; their relevance for the Farasan Islands will be investigated below. Regionally evidence suggests that shellfish exploitation was happening as far back as 9000-8000 BP until at least 5000BP around the Red Sea, 4000BP in Oman, but younger sites associated with pottery are known of in the Red Sea. This suggests that shellfish exploitation is a long-term strategy, but the scale of sites suggests that they were part of a broader subsistence strategy. The relationship of the initiation of shell middens to climatic change (from the climate data) is inconclusive, suggesting that aridification did not result in the intensification of shellfish gathering and shell midden creation. Likewise there is no significant cluster of dates during sea level stabilisation. This supports the regional data for smaller more dispersed sites, suggesting that with the exception of the Farasan Islands, shellfish gathering was less intensive and part of a broader economy.

Sites on the mainland (especially the Tihama) demonstrate that shellfish exploitation was an established part of broader subsistence strategies at least two thousand years before the appearance of shell middens on the Farasans. The Farasan Islands sites represent an intensive burst of activity not mirrored on the mainland, but possibly having analogues further afield in the Dhalaks. Rising sea level may well have obscured earlier evidence; this is unlikely on the mainland where earlier sites are located well inland on palaeoshorelines, however it is a possibility on the

Farasans since there are no earlier palaeoshorelines further inland. Just how long the Holocene Palaeoshorelines were active for before the initiation of shell mound building activity is uncertain, but at JW at least the evidence suggests that shellfish exploitation was active when the palaeoshorelines were stranded inland.

Climate deterioration in the region has already been cited as a possible cause for intensification (eg Gutierrez-Zugasti 2011), indeed no earlier sites have been found on the Saudi stretch of the Tihama Plain. However much earlier sites are known slightly further down the coast in Yemen. The presence of fishing gear perhaps indicates intensification and specialisation of coastal resource exploitation; the number of sites also increases through this period (eg Edens and Wilkinson 1998; Durrani 2005). However the Farasan Island sites do occur after an aridification of climate, and it may be possible that the intensive nature of shellfish gathering here was a response to declining resources elsewhere. Although the Farasan Island sites postdate the change in climate it is possible that it was gradual over a longer period, resulting in the gradual decline in moisture availability. The Farasan Island sites are the only obvious evidence for the intensification of shellfish exploitation in the region.

For the termination of intensive shellfish exploitation the obvious answer is that coastal change impacted upon the productivity of the shell beds bringing intensive exploitation to an end. However the shell scatters in Janaba West which appear to follow the receding sea suggest that exploitation continued despite the obvious change. At present they seem to be a localised phenomenon which did not continue long enough to reach the modern shore, or result in shell mounds when sea level was stable.

Another possible influence on fisher-gathering is the arrival of farming in the region (eg Crombé 2010). Despite the presence of domesticates on the mainland well before the Farasan sites, the full farming package is not

thought to have reached the region until around 4000BP. This likely came from Africa based on similarities in pottery design associated with the earliest farming communities and earliest pottery in the region (eg Durrani 2005). Few large shell sites are found beyond this time, suggesting that farming superseded intensive shellfish gathering. A further deterioration in climate at this time may also have put pressure on existing populations. Perhaps climate deterioration paved the way for the introduction of farming by forcing the fisher-gatherers of the region to adopt new technology. Maybe outsiders, perhaps also under stress from climate instability in Africa, were forced to migrate across the Red Sea in search of new land. Certainly if the fisher-gatherers were making trips to the Farasan Islands they would have been competent seafarers, and probably capable of making their way down the coast and across the Bab-al-Mandab to Africa or indeed to the other side of the Red Sea. It maybe that the increased scarcity of coastal resources stressed the population of over-reliant fisher-gatherers to take drastic measures and migrate.

A key question is whether shellfish exploitation was a part of the wider pastoralist economy or localised at the coasts (eg Guilaine and Collectif 2005; Bailey and Milner 2002); BHS-18 would suggest the former (eg Uerpmann *et al.* 2000). Even today many farmers operate a modern adaptation of seasonal farming on the Farasan Islands. Fields are ploughed and sown, and the crops left to fend for themselves until harvest; signs mark out claims of ownership on the land. Often these farmers spend much of their time on the mainland for employment. There are few pockets of accumulated sediments, and these are often modified with low stone walls across the contours to help retain what little rain falls. This lifestyle could be compatible with seasonal shellfish exploitation, however no pottery has yet been found in any stratified shell midden deposits. In addition the preservation of bone is bad, with only a few degraded fragments of gazelle found (as opposed to domesticated animals). Even if there were domesticates in the region at this time it is unlikely that they would have been transported c.40km across the sea on

boats (eg Carter 2006; Anderson *et al.*, 2010). However if elements of farming came from Africa across the Red Sea, they must have crossed at some point.

It is unclear how this mode of life would have been compatible with intensive shellfish exploitation on the islands, especially given the need to tend animals. It could be that these were completely separate communities, perhaps only linked by trade. The Dhalak Islands sites suggest a link which is yet to be tested. The similarities in typology between the Farasans and the mainland suggests a link, but the difference in assemblage composition also highlight differences.

The evidence presented in this thesis suggests that shellfish gathering on the Farasan was a short intensive burst of shellfish gathering activity. Although there are clear links to the mainland the activity represents divergent economic activities, with the two communities perhaps only linked by trade. It is possible that these people had links with the other side of the Red Sea where sites with a similar appearance are found; perhaps they even made season migrations to between these sites.

The reasons for the initiation of this burst of abrupt intensification of shellfish gathering is unclear. Although climatic deterioration fits well with archaeological evidence of the Saudi Arabian Tihama Plain, it fits less well with the evidence from across the border in Yemen. Here evidence suggests increasing coastal adaptation through an increasing number of sites and developing technology, however these sites are occupied over a longer period and are clearly part of a wider subsistence strategy which included pastoralism.

Although there may be other factors which have yet to be determined it is possible to create a narrative to describe the burst of intensification seen on the Farasan Islands. It seems plausible that climate deterioration increased pressure on a coastally adapted population, and that part of this population took advantage of a window of ecological opportunity on

the Farasan Islands. This opportunity was short lived, being created by a combination of coastal stability and changing climate. Intensive shellfish gathering ended due to a combination of factors. The rapidly changing shoreline is likely to have played a significant role, stranding sites inland, but more crucially impacting upon the productivity of the shell beds. Compounding this was further climatic deterioration, and the arrival of the full Neolithic farming package which superseded the earlier hunter-gatherer-pastoralist.

10.3 The Emergence of Large Shell Mounds

The presence of large shell mounds on the Farasan Islands offered the possibility help answer three interlinked questions. The question of intensification has already been addressed, where the excavation and dating of two sites helped to demonstrate intensive shellfish exploitation. The second question is why large shell mounds occur, which will be addressed in this section. The third theme of social and economic responses to local environmental change will be dealt with in the following section.

The phenomenon of a large shell mound dominating a group of smaller sites is well documented. However the reasons behind this configuration are poorly understood. This section will address the underlying causes behind the emergence of large shell mounds.

Previous work has suggested that shell mounds emerge through one of the following processes (Bailey 1994):

- That sites accumulated as a result of continuous activity from a single point of origin
- Intensification of shellfish exploitation over time resulted in the emergence of larger sites

- Over time several small sites close to one another grew and coalesced into a single larger site

Excavations have shown that both sites analysed in this thesis originated from a single point and intensification has already been dismissed. Whilst dome shaped mounds are more likely to originate from a single point, irregularly shaped or sinuous mounds are likely to be amalgamations.

The internal structures of the two excavated sites differed substantially. JE0004 has a complex stratigraphy, with two distinct phases of accumulation; the coastal side is characterised by concentrated activity represented by hearth complexes, processed shellfish, and fish and mammal bone. The inland side of the site is dominated by a secondary phase of thicker layers of larger shells. In contrast KM1057 is dominated by a homogenous mass of *S. fasciatus* shells, interrupted in only two places by *C. reflexa*/*C. ramosus* layers.

The structure of the mounds can tell us much about the processes responsible for their formation. JE0004 has two distinct phases of deposition: the coastal side which is dominated by vertical accumulation, and the inland side which is horizontally accumulated. The vertical accumulation corresponds closely to the toss-drop zone model, centred about the complex of hearths. Larger shells are commonly found away from the centre of these hearths, with smaller shells concentrated on layers ringing the hearths. The assemblage from this side of the site closely resembles a home base with a mixture of coastal resources returned to the site for processing.

The second phase of accumulation on the inland side of the mound is dominated by large shells, with pockets of smaller shells present. Although this pattern is not exclusive of the toss-drop zone model, it is more indicative of intensive processing of the larger shells, with deposition away from the centre of activity. The centre of activity still seems to have been focused towards the coastal side; however layers on

the coastal side corresponding to those on the inland side are absent. This could be because of erosion – the burials and some of the contexts suggest that the mound has been reduced in height.

The excavations at KM1057 show a rapid accumulation of predominantly *S. fasciatus* about a central point in the site. However this central point is not demarcated by a hearth or complex of hearths despite AAR dating suggesting that the shells had been heated. It seems that KM1057 accumulated through intensive shellfish processing and very little else, with heating of shells either in a different part of the site or at another location. Occasional rare fish bones from the bulk samples hint at other activities but lack any obvious features. Both excavated sites show elements conforming to the models suggested by Russo and Heide (2003) and both appear to have developed rapidly from a single point of origin.

Test pitting in a number of sites in the area confirmed that neither JE0004 nor KM1057 are unique in composition, with sites close by often having very similar stratigraphies. This would suggest that the sites are contemporaneous with similar exploitation strategies and processes of formation; indeed this is supported by the two test pit dates from the Khur Maadi. Therefore in this case the emergence of large shell mounds is not linked to intensification through time at the site, since all sites are thought to be of the same age. Therefore the most likely scenario is that large shell mounds emerged as a result of more regular and intensive use, rather than a longer history of use.

The underlying causes behind the emergence of large mounds are likely to be a combination of social and economic decisions imprinted over the framework of the landscape setting. These decisions include how the shell beds were exploited, site location and reuse. The ecological habitats supporting highly productive shell beds need to be present and it seems likely that the location of large mounds is strongly linked to the accessibility of the site to these shell beds. JE0004 is on a cliff, but is

located on a small but prominent headland which offered better visibility around the bay, better fishing opportunities, and probably better accessibility to the shell beds. KM1057 is located at the mouth of the bay offering excellent accessibility to a range of resources; its height would also offer an unparalleled vantage point in the bay. This would increase its attractiveness for reuse as the site grew.

The excavations found very different formation activities at work each of the excavated sites. The deposits at JE0004 are very suggestive of a home base with a wide range of activities being carried out, with both marine and terrestrial resources exploited. KM1057 on the other hand appears to be dominated by the processing of single shellfish species at any one time, with limited evidence for other activities. As stated earlier this suggests that KM1057 was used primarily as an area for processing shellfish, with other activities carried out at different locations.

There is a final possibility for the emergence of KM1057 and its sister site KM1055; it could be that their size is symbolic, and that deposition at the site had the deliberate aim of creating large shell mounds of monumental scale. They are highly prominent in the flat landscape; when the bay was wet they would likely have been even more imposing. It is not quite on the same scale as the shell works of the Ten Thousand Islands; nonetheless the sites are impressive markers in the landscape.

There are a number of exceptions to this apparent correlation between large sites and prominent positions in the landscape. In Janaba West on the west bank of the former bay there is a linear distribution of shell mounds along the top of a cliff. There are over a hundred sites, with 11 site over 2.5 meters; there are no obvious focal points in the landscape except the occasional shallow wadi and the large sites are not obviously associated with these. The east bank of JW shows that proximity to the shell beds is an overruling factor, with sites abandoned as soon as relative sea level change strands the sites inland. New sites are then initiated on the immediate coastline. This could be mirrored in the interior

of the KM bay, with more dispersed sites represented changes in the high watermark between seasons. Larger sites may also have become self selecting dry sites at times of higher water.

The deliberate deposition of shell to create large mounds located in prominent positions in the landscape overlooking important resources could be a factor. One possibility arising from the emergence of large shell mounds is the symbolic ownership of resources through markers in the landscape. The emergence of large shell mounds such as KM1057 may be an expression of ownership over the local resources, such as productive shell beds. In other regions of the world shells have been used as a building material (eg Vernon and Knight 2004; Khalidi 2008; Schwadron 2010a, 2010b), and it may well be that not only is KM1057 a processing site, but one that was deliberately developed and built up in order to make a statement in the landscape.

Perhaps the reason why KM1057 and KM1055 became such visible mounds is simply a product of their location and the accessibility of the sites to highly productive shell beds. These sites occupy prime locations, right at the mouth of the bay. They have excellent access both to the interior of the bay, out into the mouth of the bay via the spit, or out onto the open coastline via the small cliff on which they sit. Thus these sites are likely to have been more frequently visited than others, and therefore more likely to accumulate into larger mounds. If the mound was formed as a result of the use of shell as a building material it is likely that such an accumulation would occur at an important location, close to the resource and where it is most accessible.

Sites such as these might also become self-selecting markers in the landscape, whereby they show the presence of productive shell beds and act as an incentive to further reuse of the site. Further to this they would also have been visible from off-shore when the community were at sea.

The underlying cause for the emergence of large shell mounds on the islands is complex. Whilst the emergence of JE0004 and KM1057 appears to be correlated to prominent places in the landscape, the same cannot be said for the sites of Janaba West. However the dating suggests that the JW sites may be from a slightly earlier phase of activity, perhaps signalling more repeated or higher intensity use of the JW sites.

The emergence of large shell mounds on the Farasan Islands is linked to intensive repeated use of the same site over relatively short periods. Location is crucial in most cases; with access and proximity to resources the highest priority as demonstrated by the JW scatters.

Sites such as KM1057 may have become self selecting sites since their height would offer an additional advantage as a vantage point. Large shell mounds dominate most groups of shell mounds on the islands with few exceptions. It would be tempting to cite location as an underlying cause for why large shell mounds emerge. To some degree this is true since large shell mounds are sited adjacent to highly productive shell beds where intensive shellfish exploitation can occur. However not all large shell mounds are located in prominent positions in the landscape such as headlands or the mouths of bays. Prominent locations can become a focus for shellfish processing, since they often offer better access to these resources.

10.4 Social and Economic Activities

The social and economic activities of the Farasan Island shellfisher-gatherers can be broadly reconstructed using the evidence from this thesis. In addition it has also been possible to reconstruct responses to changes in the environment to determine how people modified their behaviour.

The social and economic activities of the fisher-gatherers of the Farasan Islands have been reconstructed using the information derived from this

research. There has been very little cultural material found in any of the excavations, which is not surprising given the abundance of shell on the sites. Items found are often unstratified; however these suggest a broad agreement with mainland sites, being composed of basalt or more rarely obsidian. Grind stones and axes are also present, these are made of granites (eg Edens and Wilkinson 1998).

Reconstructing the economic activities poses less of a problem than the social, although it is still hard to assess the story as a whole since the information is biased towards activities carried out at the shell midden sites.

Intense exploitation is testified by the number of sites (2811), and the volume of shells contained within the sites. As suggested in the results, the estimated total quantity of shellfish in sites across the islands (370,000 – 1,325,000 tonnes) is colossal. If all of these sites do indeed originate from the same phase of shell mound building, then it would represent a very intensive episode of shellfish exploitation. Depending on the duration of exploitation and the extent to which shellfish contributed to the diet this much shellfish would be enough to feed between 78 and 2220 people a day for 600 or 300 years respectively. The lower end of the estimate is more probable, and it may well be spread over a longer period reducing the number further still. However this still means that it is possible for a small community of people to remain on the islands year round subsisting on shellfish and other coastal resources (eg Meehan 1977; Erlandson 1988).

The same calculations show that both JE0004 and KM1057 would not have provided enough food derived from shellfish to support a group year round. Therefore they must have been visited periodically and the site would have been part of a broader exploitation strategy. Links with the Dhalak Islands have already been postulated and the divergence from the mainland in the composition of shell and lithic assemblages has also been discussed. It therefore seems probable that these were a distinct

community of fisher-hunter-gatherers who were not engaged in the pastoralism-hunter-gathering which occurred on the mainland.

The most challenging aspect is relating evidence and activities on the islands to those on the mainland. Although dating allows a broad assessment of their temporal relationship, the assemblages have marked variations.

Whereas up to 75% of mainland lithic assemblages are composed of obsidian only two obsidian artefacts have been found on the islands, the rest are composed mainly of basalt with shell and granite components also present (eg Edens and Wilkinson 1998).

The key similarity is the presence of grindstones, which suggests (but does not necessarily imply) processing of wild grasses and cereals. Given the relative scarcity of such plants on the modern islands it could be that these were used for processing other products (both marine and terrestrial) or perhaps it is a sign of climate change. Alternatively it is possible that such items were valuable and so carried to the islands from the mainland during seasonal travel rather than cached.

Despite the changes in climate the number and scale of the sites appearing at this time do not suggest that shellfish became a primary resource. They were probably still utilised in a similar manner as they were at the earlier shell sites JHB and ASH, supplementing diet as part of a wider subsistence strategy.

A key question is how did the fisher-gatherers reach the islands? It is possible that they were an “endemic” population trapped on the islands by Holocene sea level rise. Although the data suggest that the shell middens represent enough food to support a small population year round there are several strong arguments against this. The presence of stone tools made from mainland stone is the strongest; the absence of any sites dated before this period could be due to sea level rise.

Typological links to the mainland suggest contact, even if the composition of assemblages is divergent. The additional evidence of very similar sites on the Dhalak Islands requires further investigation; however the communities must have been competent sea farers to voyage c.40km across open water punctuated only by occasional islands. They could have reached the Dhalaks by directly crossing the Red Sea (a voyage of c.130km) or they could have followed the coast and crossed at the Bab-al-Mandab in a series of shorter open water crossings.

10.4.1 Central (and Persistent) Places in the Landscape

There are a range of different types of site on the islands, from home-base camps such as JE0004 to sites dedicated to intensive processing of single species such as KM1057. This could be due to local environmental factors, or possibly that the sites originate from different phases of activity. The dating suggests that the two excavated sites overlap, therefore it is probable that different activities were taking place at different sites related to the locally available resources.

The phenomenon of shell mounds accumulating over several hundred years is a result of permanent places in the landscape. These sites were not permanently occupied; this is underlined both by the calculations of nutritional value for excavated sites, and by findings of root systems from (palaeo)surface horizons within test pits in Janaba West. These suggest periods of abandonment when vegetation took hold. It is not uncommon for plants to take hold in and around settlements especially in areas that are not actively occupied; plants in arid areas are also preadapted to rapidly exploit moisture availability. However the excavated sites although supporting discontinuous occupation, do not have obvious abandonment deposits. The varied nature of deposits in JE0004 suggests a central place, used to process resources procured from beyond the immediate area (eg Bird 1997; Houston and McNamara 1985; McNiven 1992; Thomas 2002, 2007; Olsson *et al.* 2008).

The stratigraphy of JE0004 indicates that each processing event is linked with a specific species or combination of species, suggesting that habitats were targeted systematically (eg Bird *et al.* 2002; Cannon 2003). Even though it was probably only used for short periods through the year JE0004 has post holes suggesting wind breaks or sun screens, unlike KM1057. This suggests that the home-base of JE0004 was probably lived on, whereas KM1057 was probably only used for processing (although it is hard to distinguish post-holes in a uniform material).

JE0004 has the widest range of activities present, from the most visible shellfish processing to fishing, hunting, and gathering of wild plants. The post-holes hint at that erection of temporary structures, probably around the hearths which probably formed the focal point of activities. It has been shown that heating was a key step in the processing of *S. fasciatus*, even at KM1057 where evidence for hearths was rare. The burials could post date occupation of the mound, however it is highly likely that they are associated with the final phase of deposition given that the dates are so close.

A key mechanism of deposition which appears to have occurred at many sites is the toss-drop model, focused around a central hearth. The notable exception to this is KM1057, where no hearths were found, only a single layer of ash in the upper layers. However the site still conforms to the model proposed by Russo and Heide (2003) implying that activity was focused on the centre even if there is no evidence of hearths or other features.

The location of the sites KM1057 and KM1055 are prominent in the landscape and centrally located amongst local sites. The location at the mouth of the bay may have offered the easiest access to the abundant resources of the *S. fasciatus* beds.

One of the underlying processes of site formation in hunter-gatherer communities has been identified at a number of sites. The toss-drop zone

model is easily applicable to shell processing, especially for different sized species. However as already mentioned it is useful to consider that some deposits may be palimpsests. This model leads on to the formation of sites, where again JE0004 conforms to models which have been proposed for the formation of shell middens. Russo and Heide (2003) suggested that for a shell-ring site in Florida accumulation was first vertical, before being superseded by horizontal accumulation first on one side of the mound, and then the other. In their case study this eventually formed a ring shaped mound with a hollow centre. On the Farasan Islands the predominant site shape is domed, with the direction of growth of many sites (including JE0004) constrained by cliffs. KM1057 does not seem to have been restricted in this way, although the section suggests slightly greater accumulation on one side despite the dominant vertical deposition.

The presence of mammal bone (probably gazelle) within several sites suggests that hunting was also an important economic activity for the Farasan fisher-gatherers. As mentioned earlier, grind stones suggest (but do not necessarily prove) the processing of wild grasses, a precursor to agriculture. Evidence such as net weights on the mainland suggests that coastal resource exploitation was intensifying, and new technology was being employed to increase yields and perhaps target new prey species. The typology of net weights found at these sites is convergent with that found along the northern and eastern coastlines of the Arabian Peninsula, notably Oman. It may be that these items, or the knowledge of how to manufacture them, arrived through contact (whether direct or indirect) with communities from the Omani coastlines. The presence of the Arabian Bifacial Technology certainly suggests so, although it has been argued that this was a distinct coastal lithic tradition (Uerpmann 1992; Edens and Wilkinson 1998; Edens 2001). However one key component of the Omani toolkit that is missing (or at least has not yet been found) is fish hooks. These objects are distinctive (easily identifiable), being made out of shell. There are several key typologies of fish hook which are readily identifiable (from the method of tying the hook to the line to the

shape of the hook itself) however none of these have yet been found in the Red Sea. Given the presence of one tool (net weights) the other (fish hooks) would also be expected, and it may be that the excavations to date have either not been large enough, rigorous enough, or have simply been unlucky. Another possibility is that locally available fish were shoaling palegic species, not seabed predators, so nets were more effective than hooks.

As already seen the nutritional value of shellfish from JE0004 indicate that there is not enough shellfish to allow for continuous occupation, even for one person based on a mixed diet. This strongly suggests that the sites were permanent places in the landscape, visited repeatedly over successive years. However the sites need not necessarily be visited every year, but may have been used as a part of a wider exploitation strategy moving to a different coastline each season. Using the example of *S. fasciatus* in JE0004, layers 30 and 37a give average lower and upper limits respectively for *S. fasciatus* dominated deposits. They have estimated volumes of c.0.66m³ and c.3m³ respectively; using average calculations it can be estimated that there are 25'000 and 110'000 individual shells in each layer. These would yield a minimum of 50kg and 225kg meat for each layer. This is enough for 20-90 meals respectively, if shellfish meat alone is the diet. However for a group of people this is only a few days worth of food, before the shell beds are stripped and it would be necessary to move on.

If the density is estimated at 20-50 shellfish per meter square (based on rough field estimates), these layers would be composed of shellfish gathered from an area of 500-2250m². The shallow subtidal margin here is c.100m wide; even if *S. fasciatus* densities were much lower there would still be ample habitat to collect these easy to exploit shellfish. This demonstrates the importance of *S. fasciatus* gathering as an economic activity.

The bulk samples show variation even with single contexts, where two samples from different areas of the same context would have markedly different MNI values for *S. fasciatus*. This demonstrates that although a deposit may be visually continuous this can mask underlying spatial differences within the deposit. It could be a result of discreet events, or it may be that one sample was closer to the focus of processing, therefore receiving a greater number of the fragile apices (eg Berg 1975, 1976; Meehan 1977; Osbourn 1977; Roberts and McKenzie 1983; Erlandson 1988).

The primary method for shellfish processing seems to have been heating and smashing, although trampling could also account for some of the fragmentation seen (eg Mowat 1994; Schmidt *et al.* 2001). This is even true for KM1057 where the majority of samples showed evidence of heating, even though evidence for hearths was rare.

An interesting feature found on Southern Saqid was the presence of a small hearth pit with inverted specimens of *S. marisrubri* inserted into it. This site has yet to be dated, however it shows a different form of hearth not observed elsewhere on the islands. That the site was associated with an inland palaeoshoreline suggests that it is contemporary with prehistoric shellfish gathering on the island. It is suggestive of a modern technique of burying fish to cook them.

10.4.2 Overexploitation

It has often been suggested that intensive shellfish exploitation would result in a decrease in shellfish size due to the removal of the largest individuals by foragers (eg Faulkner 2010). In the case of the Farasan Islands the shell size for *S. fasciatus* remains relatively constant through the deposits of both excavated sites (Eva Laurie pers. comms. 2010), with only small deviations in the size of the shellfish over time. These deviations are not statistically significant (with the exception of two samples from KM1057 which are significant, and could be the result of

environmental or tectonic factors rather than over exploitation) and the range of shell size at these sites is relatively narrow.

The possibility of overexploitation at both excavated sites has already been investigated, however the most abundant species, *S. fasciatus*, shows no signs of decrease in size over time. This does not necessarily rule out overexploitation since the bioproductivity of these coastlines is very high, and recovery rates may reflect this (eg Jerardino 1997; Zuschin *et al.* 2001; Zuschin and Oliver 2005; Braje *et al.* 2007; Morrison and Hunt 2007; Braje and Erlandson 2009; Faulkner 2009; Erlandson *et al.* 2008, 2011). There is a notable and statistically significant size difference between *S. fasciatus* from JE0004 and KM1057. This is likely to be due to differences between the habitats – the coastline is open and less sheltered around JE0004, limiting shell size, whereas the coastline around KM1057 would have been more sheltered allowing greater size.

The Farasan Islands are a designated marine protected area; however some forms of overexploitation are still endorsed by the government. The Harid Festival (Gladstone 1996) likely has its roots in much older traditions; how much older is uncertain. There is no current evidence to suggest intensive prehistoric exploitation of the Harid fish occurred, however ethnographic evidence suggests that this type of resource is likely to have been targeted if it existed. Modern day events often have their roots in antiquity, with people carrying out acts with no perception of the original reasons behind it (eg Edmonds 2002). However to exploit a fish with such intensity requires no ritual other than to arrive at the location at the correct time of year (by lunar calendar) with rudimentary equipment to scoop up the fish. It is therefore likely that this is an old tradition, perhaps as old as the shell middens, if the fish have always spawned in this area. Future research in the area will attempt to locate possible sites for mass fish processing, with the goal of assessing prehistoric and modern impacts on the Harid fish (*Hipposcarus harrid*) population. It could be that the shell sites are a prehistoric precursor to these modern events.

Local islanders tell stories of how it was before the festival became developed, with people using nets to catch the fish on a small scale. The fish were often dried so that they could be stored. There has been no investigation of this phenomenon, and no record exists of how long this has been going on for. What this does show is that seasonal migrations to the islands have been undertaken in at least the recent past. It is not hard to imagine that seasonal migrations of this type may be an ancient tradition. Indeed the presence of fish and mammal bones within shell midden deposits suggests that shellfish were exploited as part of a wider subsistence strategy which utilised many resources across the islands.

10.4.3 Burial and Site Reuse

The child burial has an overlapping but slightly younger date to the deposition model for the site. However the youngest part of the site has not yet been dated due to sample failure. It may be that it is contemporaneous with the final stages of site use, or it may be a slightly later insertion. Although only fragments of skull and a few milk teeth were preserved this burial offers some interesting insights into the social nature of the island's communities at the time shell mounds were accumulating, or soon after abandonment. The hammer stone placed beneath the skull and the unusual shells associated with the burial suggest a ritual aspect, in addition to the act of burying the deceased. Before the hammer stone was inserted into the grave, the cut was lined with charcoal – whether this is evidence for burning within the cut prior to burial, or burning elsewhere with the resultant charcoal redeposited is uncertain. However given the young date it is consistent with ritual behaviour. Although the child was buried facing inland (in contrast to the adult) the close association with the adult burial is suggestive of a link between the two.

The adult burial was buried in an upright seated foetal position, facing out to sea. Differential preservation of the bones resulted in many being lost (if they were there at all), whilst others were present only as stains. The vertebrae were not preserved, but the long bones of the arms and legs

fared better. The burial also suggests that the mound has been eroded, since the shoulders and skull would have been protruding through the top of the mound had they been present. All bones were articulated, which would suggest that the skeleton was (at least) largely complete when buried. No dating samples were recovered from this burial due to the conservator digging it out without recording or sampling it.

Many shell mounds around the world have burials inserted into them; indeed it is often the norm (eg Luby 2004). However whereas these often form part of the fabric of the site, the burials in JE0004 seem to have been inserted through the upper layers, and may represent final deposits for the site. There are very few areas of soft sediment on the Farasan Islands, therefore burying within shell mounds would seem a sensible choice (other than building a cairn, of which none have been observed). It may be that these are not sealing burials, and the *lost* upper layers might have themselves sealed in the burial. Only dating of the youngest surviving part of the site will help answer this question.

The discovery of burials in other shell mounds around the Arabian Peninsula has been sporadic (eg Tixier 1980; Hublin *et al.* 1988; Boucharlat *et al.* 1991; Vogt 1994; Uerpmann and Uerpmann 1996; Kieswetter 2003; De Beauclair 2008). The configuration of these is variable, with grave-goods often absent (eg Kieswetter 2003).

Intrusive graves from later periods are not the only types of reuse of shell mounds sites seen on the islands. One of the most common re-uses of shell mounds on the islands is for coral block structures to be erected on top of mounds. Some are square, whilst others are circular. Both types of reuse appear to be associated with pottery scatters; although it is hard to associate the pottery and coral blocks without more detailed investigation. Different phases of reoccupation of the sites result in a complex palimpsest where finds of different phases can be found in the same context – ie the surface context. Given the intrusive nature of the coral blocks (they have been inserted into the tops of the mounds into cuts)

and that the ceramics are only found on the surface (test pitting revealed no pottery present below the surface within the constraints of the test pits) they are interpreted as later reuse of the sites. In one case a mosque was found on top of a shell mound, its outline marked with coral blocks similar to the other enclosures but larger.

Stone block structures come into use the region in the Bronze Age at around 4500BP, or slightly earlier at SRD in Yemen. However their use continues well into modern times, therefore typologically it is hard to date these structures. Fortunately they are often associated with pottery scatters, samples of which have been submitted to the Jizan museum for curation and analysis.

Shell mounds are still being reused and reoccupied in the present day. Several Triangulation Stations have been located on shell mounds across the islands. These proved useful in the survey to calibrate the GPS machines.

Another modern use of shell mound sites is as picnic sites, which results in the deposition of modern shells. *C. ramosus* and *P. trapezium* are considered a delicacy by modern islanders. They often take their families out on picnics to the coast and gather these shellfish from the intertidal and shallow subtidal areas. The shell mounds form useful vantage points on which the family can have their picnic whilst taking in the view. This reuse perhaps echoes the Neolithic use of the mounds, family units grouped around a focal point, in Neolithic times a hearth, in modern times a barbeque. An interesting study would be to investigate a modern deposit and assess the similarities and differences between the two deposits (this was not within the remit of this thesis, but will be followed up in further research in the future). However the comparisons do raise some interesting questions. It is assumed that once the sea retreated from the palaeoshorelines leaving the shell mounds stranded inland, that the sites would have been abandoned. However since modern populations reuse these sites because they offer vantage points, it raises

the possibility that the shell mound builders perhaps continued using the sites after the sea had retreated. The evidence presented earlier in this section from JW suggests that this was not the case, and that shellfish processing still occurred at the closest available location to the shell beds and water.

Further work is needed, since the Gandeel Peninsula Kinetics test showed a much younger AAR age for a sample from a site located on a palaeoshoreline. This date could either represent the abandonment of the site, or reuse at a much later date. Given that all of the other palaeoshorelines date to the same phase it is probable that this is a case of site reuse rather than an unconformity along this section of coastline; however more work is needed to test this.

10.4.4 Gender

Gender archaeology has become important recently (eg Gero and Conkey 1991; Zeanah 2004), with gender in shellfish gathering highlighted as an issue by a number of researchers (eg Claassen 1991), notably on the NW Coast (Moss 1993). It has been recognised that information on shellfish gathering derived from ethnographic sources may not be suitable analogues, since shellfish are often viewed as either a food source for the lower social ranks, or are influenced by andocentric ideologies. Therefore shellfish are often underrepresented in the ethnographic record (eg Moss 1993; Faulkner 2010).

Shellfish gathering has been shown to be an activity often carried out by the women of a group (eg Moss 1993). It can be highly productive, with some studies showing that enough shellfish can be gathered to feed a single person in as little as two hours (eg Meehan 1977). Children, the elderly, and the infirm can also participate in the activity provided that the resources are easy to access (eg Bird and Bliege Bird 2000, 2002).

The theories from these studies could be applied to the Farasan Islands, where women might gather the *S. fasciatus* which is highly abundant and easily gathered. The men on the other hand might be engaged in activities such as fishing, or hunting gazelle. It is possible that this might extend into the marine realm, where harder to gather species might also be collected by males. This implies that there was a gender division in shellfish gathering, with *S. fasciatus* being associated with women, and *C. reflexa* associated with men. Certainly in the Khur Maadi we see a division, with many sites either composed of *C. reflexa*/*S. marisrubri* or of *S. fasciatus*. There is of course some overlap, and a good number of sites which are composed of both. However other studies have shown that women also participate in diving and fishing (eg Arunotai 2008). This demonstrates that different communities can have very different societal norms, and that each community must be treated as unique. Speculation about gender division is just that, guess work based on observations from the other side of the world.

Shellfish gathering has often been called an easy economic activity, which even the weak or frail could engage in. However analysis of the species found in many of the shell middens on the islands shows that this is overly simplistic. These species can be divided into two groups, those easy to gather, and those requiring greater skill and physical fitness. The former group is composed of species such as *S. fasciatus* – which graze in high densities on sea grass in shallow subtidal water. *C. ramosus* and *P. trapezium* are prevalent on rocky intertidal and subtidal substrates. Even children could engage in gathering these species. The harder to gather includes species such as *C. reflexa*, *S. marisrubri*, *P. nigra* and *Tridacna* sp. (all are bivalves which cement themselves to the substrate). *C. reflexa* grows at depths in excess of five meters, therefore requiring diving to gather; *S. marisrubri* grows two meters more, likewise *Tridacna* sp. is most commonly found in this range. Although *P. nigra* is present from one meter down, it is more prevalent in deeper waters.

Exploiting such hard to access resources may also require special adaptations. Most people have very poor vision underwater which would make it hard to locate and gather such resources. This is compounded by the fact that *C. reflexa* and *S. marisrubri* cement themselves onto the coral terraces making it necessary to use force - either an implement (ie piece of rock) or a well aimed kick to break off.

Such adaptations have been found and quantified in fisher-gatherer communities. The Moken fishermen of Thailand and Burma dive up to 20m for several minutes and have learnt to manipulate their natural eye reflexes by controlling pupil movement to allow them to have better vision underwater (Gislén *et al.* 2003). This would greatly increase the efficiency of intensive exploitation of deeper water shellfish species.

Whether exploiting hard to access species was a choice of necessity or a matter of taste is uncertain (eg Cameron *et al.* 2008). Nevertheless given the abundance of *S. fasciatus*, *C. ramosus*, *P. trapezium* and other shellfish it does seem unusual that so much effort was invested in the gathering of *C. reflexa* and *S. marisrubri*. This is a specific marine adaptation, taking a lot more effort than the shallow water species to gather. It may be that these latter species have a particularly desirable flavour, or were considered a delicacy by the shell mound builders. Although their shells appear to be useful shapes, easily adaptable into tools, no evidence of shell-tool manufacture has been found. Perhaps it is a sign of need, once easier to exploit resources (eg *S. fasciatus*) had been stripped the harder to access resources were targeted. The high bioproductivity of the island's waters would ensure that within a couple of years shellfish stocks along that stretch of coastline would be replenished. However there little evidence for overexploitation; species from both habitats are often found within the same layers. Also the shell size measurements for *S. fasciatus* do not indicate substantial reductions in size through time as would be expected for overexploitation. It could be that a stretch of shoreline was systematically stripped of shellfish in a single event, before the group moved on to the next section of coast (eg

Bettinger *et al.* 1997). If they returned in a year or two the shell beds would have recovered, meaning that no decline in size would be evident.

10.4.5 Increased Mobility

The location of the Farasan Islands 40km from the mainland necessitates the use of sea faring vessels (eg Boivin *et al.* 2009). Does this mark an increase in mobility of the populations or is it a continuation of a mobile lifestyle? Many sites display coastal-terrestrial signals, but does this mobility extend into the coastal realm? The low level of lithic scatters (the lack of sediment or vegetation cover means that spotting them is relatively easy whilst on survey) could be indicative of trade in prestige items rather than a direct transport as part of seasonal movements (eg Bourke 2002; Fattovich 2004; Ambrose 2006; Carter 2006; Boivin and Fuller 2009; Khalidi 2009). The sources of many rocks is over 100km along the coast, it is possible that this distance was only travelled when the need arose rather than as part of a seasonal movement. Mainland sites tend to have a greater abundance of lithics than sites on the Farasans. It seems unlikely that seasonal movements on this scale were compatible with domestic animals, but it does not necessarily imply that the whole community was involved in the migration across the sea. This mode of subsistence would support intensive processing of shellfish for storage rather than immediate consumption.

The site of Al-Birk features the same basalt lithic technology, with the mound made up of *Anadara* and *C. ramosus* shells (Bailey *et al.* 2007a; Bailey *et al.* in press a). Although not direct evidence of a link it appears to be of a similar tradition. A key indicator would be the presence of deeper water species, which has not yet been found.

Seasonal sea faring could have been enhanced by changing wind and currents, which vary seasonally. During summer these move south through the Red Sea, being reversed in winter (eg Munro and Wilkinson

2007; Boivin *et al.* 2009). This would facilitate movements of communities up and down the coast in each season following these patterns.

The use of boats seems implied given the evidence of lithic tools made of material derived from mainland sources, some of them distant. Likewise the distance between islands in the archipelago are large enough suggest the use of vessels, rather than swimming. Evidence around the Arabian Peninsula also points to the use of boats.

The excavations recovered a notably small number of worked artefacts, with only one stratified lithic tool found, beneath the skull of the child. The volume and likely rapid accumulation of the sites are a possible reason behind this scarcity. Many shell sites not only contain lithics but worked shell (eg Balter 2006; Bar-Yosef Mayer 1997); despite rigorous screening of all excavated material no stratified finds of this type have been found.

It is clear that water was not the obstacle; therefore how the island communities related to those of the mainland needs to be addressed. The weight of evidence suggests that the island populations were specifically coastally adapted, with parallels to mainland communities; it is unlikely that they were farmers, however this is not unfeasible.

10.4.6 Social and Economic Responses to Environmental Change

Behavioural responses to environmental change are of significant interest for archaeological research (eg Cannon 2000). In the case of the Farasan Islands combining climate records with the archaeological record has not been possible, and only vague inferences have been possible. However it has been possible to reconstruct coastal change on the islands which has been driven by tectonic forces, and its impact on the local environment.

This has been successfully tied into the archaeological record to enable an assessment of the social and economic responses to this change.

There are three possible causes for the coastal change experienced on the islands: hydro-isostasy, salt tectonics (Davison *et al.*, 1996; Heaton *et al.*, 1996; Jackson *et al.* 1996), and rifting tectonics (eg Chappel *et al.* 1998; Prins and Postma 2000; Vita-Finzi and Spiro 2006). Mobile salt and salt domes are likely to be the primary force, but this could also be linked to hydro-isostasy, whereby additional loading from rising sea levels could have increased the pressure on the salt. This could help to explain some of the uneven movement across the islands, and also its punctuated nature of the change as seen at Janaba West. Larger scale tectonic influences from the rifting cannot be ruled out, since many coastal sites around the Red Sea have been uplifted substantially.

Coastal change is demonstrated by the extensive palaeoshorelines around the islands. The three geoarchaeological investigations have shown uplift to have occurred on a range of scales from 2-15m.

The most conclusive social and economic response to this change was found at Janaba West, where a number of shell scatters appear to follow the retreating sea. Although these sites have yet to be dated they clearly post-date the shell mounds inland. They show that people were still visiting this section of coastline after change had occurred, and were gathering shellfish. The species they targeted had changed from *S. fasciatus* to *C. ramosus* and *P. trapezium*; this is most likely a consequence of the changing geomorphological conditions.

A similar change in target species has also been seen in JE0004 and is associated with a change in formation process from vertical to horizontal accumulation. Although evidence for uplift along this section of coast is absent it is probable that a change in water depth resulted in a change in substrate type. The more extensive sand covering was reduced to pockets and with it the balance of species changed. The change in

formation processes is also likely to be linked to this, since *C. ramosus* and *P. trapezium* are larger and form a less stable surface, therefore being thrown to the periphery of the site rather than dropped in situ as with *S. fasciatus*.

The Khur Maadi also shows extensive change, although the dating suggests that a productive shell bed was present in the outer bay after the cessation of shell mound building activity. The inner bay was clearly a lot more unstable and it is likely that the dispersed distribution of sites in this area documents different water levels at different times. It is also possible that changes in the composition of KM107 represent responses to either changing conditions or overexploitation, since the two habitats exploited are very different. However this is yet to be proved, and the shell size of *S. fasciatus* through the mound does not change suggesting no negative impacts on their habitat, or on their population ecology.

The case studies described above all demonstrate responses to environmental change whilst retaining permanent places in the landscape. Changing conditions did not result in the cessation of shell mound building or the abandonment of sites. People responded by adapting their behaviour and targeting new species. In the case of JW the sites were abandoned as the shoreline moved further away, but the wadi acted as a focal point for this activity.

The dating evidence also suggests that different groups of sites may have been active at different times. The west bank of JW which features large shell mounds is possibly an earlier phase which predates the KM sites. Further work is needed to clarify this; if it is a true representation then further geoarchaeological work needs to be undertaken to determine any underlying causes for site abandonment.

10.4.7 Section Summary

The evidence gathered in this thesis has been enough to reconstruct some of the social and economic activities of the fisher-gatherer communities of these islands. In addition it has also been possible to piece together some of their responses to changing conditions.

Shellfish gathering on the islands was not limited to a single process with both home-base camps and specialised processing sites present. A range of activities at the home base camp of JE0004 suggest a broad based coastal exploitation targeting a number of resources, of which shellfish is the most visible. This is consistent with other studies, not least because focusing on shellfish can cause protein poisoning. These sites are also consistent with periodic use rather than permanence, and were most likely part of a wider exploitation strategy moving through the landscape and around the coastlines systematically targeting resources.

This movement is not likely to have been restricted to the islands, with links to the mainland present and perhaps even further afield. This movement hinged around permanent places in the landscape which were repeatedly visited over generations. Even when large-scale change altered the landscape the same stretches of coastline were still visited even if it meant a change in the species availability of that site. The JW scatters showed that even where the retreat of the sea occurred, the same stretch of coast was still exploited and the sites relocated closer to the shell beds.

10.5 Impact

A recent paper by Balbo *et al.* (2011) calls for more interdisciplinary work on shell middens. One of the key outputs from this project is the interdisciplinary approach used to investigate these sites. It builds on work by researchers such as Van der Schriek (Van der Schriek *et al.* 2007a; 2007b; 2008), integrating new ideas and techniques. Some of

these are more applicable to this region than others (eg Kennedy and Bishop 2011); however their transferability has already been demonstrated through the location of new sites within the wider region.

The literature review has built upon previous work (eg Edens and Wilkinson 1998; Durrani 2005) in compiling data on climate and dated shell midden sites for the Arabian Peninsula and adjacent coastlines. These have been used to create models for climate change and the timing of shell midden sites to help determine if there is a correlation between timing and the emergence of shell middens. This has helped to put the Farasan Island Shell Sites into their regional context, and also to put the regional sites into a more cohesive context.

The distribution of shell middens on the islands has largely been resolved, although many of these still need to be field surveyed. Likewise linkages between site formation and changes in the local geomorphology have been identified, but need further work to fully define. The formation processes and rates of formation for the two excavated sites has largely been determined, however there is room for future work especially with the youngest and oldest deposits of JE0004. Whilst the use of Bayesian to interpret and streamline series of radiocarbon dates is nothing revolutionary it has proved useful in determining the rate of formation. Likewise it was fundamental in calculating the LMRE for this time period.

Linked into this is development of the AAR technique for this region. This needs further work, however the investigations here have proved useful, with AAR providing an alternative and complementary chronology to radiocarbon dating.

One of the key impacts of this research is the development of a model for site location prediction. This has been achieved via the multidisciplinary technique and has resulted in the location of potential sites across the region. This is vital not only for future research of Holocene sites where

changing tectonics or geomorphology has altered the landscape, but also earlier submerged sites.

10.6 Chapter Summary

This chapter has shown that the shell sites of the Farasan Islands are the result of a short burst of intensive exploitation. This may have been broken down into different phases associated with different stretches of coastline. The emergence of large shell mounds on the islands is result of a number of different activities and formation processes, with location proving an important factor in many but not all sites.

Strongly associated with the theme of intensive shellfish exploitation and the emergence of large shell mounds are the formation processes at work within a site. The two excavated sites have shown differing formation processes and pathways to the emergence of large mounds, associated with both home-base activities and specific processing sites. These processes are strongly influenced by local factors and respond to changes. Changes in social and economic behaviour in reaction to coastal change have been observed and to some extent quantified.

The social and economic activities of the fisher-gatherers have been largely deduced, and it has been possible to reconstruct some of their responses to the dynamic nature of island's coasts.

Chapter 11

Conclusions

11.1 Conclusions

The concluding chapter will first address what this thesis has achieved, followed by its limitations and opportunities for future research.

This research has contributed a better comprehension of Holocene shellfish exploitation for the region, adding a new dimension to the understanding of intensification in the archaeological record. It has also contributed to the wider understanding of shellfish exploitation and formation processes in large shell mounds, and expanded the applicability of an existing dating technique, AAR. The use of modern local marine reservoir corrections in radiocarbon dating calibration has also been questioned.

The primary research aim was to determine whether the shell sites on the Farasan Islands were a result of continued low-level shellfish exploitation through the Holocene or a short burst of intensive activity. The spatial distribution of sites suggests that the majority are associated with the extensive palaeoshorelines of the islands. These palaeoshorelines suggest that shellfish exploitation was targeting a window of opportunity when a productive ecological habitat was created. The number of sites also suggests intensive exploitation. The excavation of JE0004 and KM1057 revealed formation processes which appear to represent repetitive re-occupation of the sites with a focus on intensive shellfish processing. The dating of these sites proved the site use to be relatively short, with the amount of material present at each site suggesting short repeated intensive use. These dates broadly correspond to aridification, suggesting that the Farasan Island sites may be a response to climate change. Dating a wider range of sites from test pitting suggests contemporaneous activity that supports the hypothesis for intensive exploitation. However it also raised the possibility of multiple successive phases, perhaps driven by local geomorphological change.

The geoarchaeological investigations revealed extensive coastal change, with evidence for punctuated equilibrium. A number of sites were discovered which appear to demonstrate social and economic responses to sea level change. Determining social and economic responses to coastal change is another key theme for this thesis. In Janaba West shell scatters were found to track the withdrawal of the sea from the main palaeoshoreline of shell mounds. This shows permanence in the landscape but a willingness to process shellfish at the closest convenient location to the shell beds. In JE0004 there was evidence for responses to local geomorphological change, where a change in composition of the site was accompanied by a change in formation process. This was most likely driven by sea level change and a change of local shellfish habitat. Changes in species composition in KM1057 could not be conclusively linked to coastal change because the accumulated sediments in the bay proved to be much younger.

The social and economic practices of the Farasan fisher-gatherers have also been tentatively reconstructed. The home-base site of JE0004 offered the best evidence, which was complemented from finds across the islands. Evidence for the heating of shellfish from AAR analysis was amongst the best findings. The volume of shell material in the sites is massive and could be used to support both seasonal and permanent exploitation on the islands. However individual sites only contain enough material for several weeks' intensive exploitation a year. Contact with the mainland evidenced from the lithic technology is very telling; however the differences between assemblages from the mainland and islands suggest that communities may have diverged. Wider links cannot be ruled out with similar shell midden types present on the Dhalak islands, although these have yet to be provenanced.

The results summarised above offer new insights into shell midden archaeology, using a broad multidisciplinary methodology to reveal new information on prehistoric Holocene shellfish exploitation in the region of the Farasan Islands. This thesis offers a model for the prediction and

location of shell midden sites, building on previous research on the location of fishing sites.

The thesis has also offered a critical assessment of the use of modern Delta R values for calibrating archaeological samples and a new value of Delta R for any future research of these sites. The development of the AAR technique for the region is another dating tool of wider significance, offering both a ready calibrated shell species, and a protocol for the development of further species, with a specific reference to sites where archaeological heating may have occurred.

The thesis has addressed the research questions and provided a wealth of new information on shellfish exploitation. However it is not without limitations and has also raised a number of questions which require future research to clarify. The limitations can be described in terms of the number of sites not surveyed, not dated, and not excavated; are the results presented here a representative sample or are they too few? The errors in the dating methods also pose problems for the interpretations when dealing with short lived events.

11.2 Future Work

There is a huge potential for future work on the islands and in the region, and further work is needed to address the limitations of the research presented here.

In terms of survey there are still over a thousand sites which have not been visited (or ground truthed) and need to be field surveyed. Many of the sites surveyed as part of this PhD only had single GPS points assigned and need to be revisited, measured and recorded. Many of the remoter islands will pose greater problems, particularly those located in between the Farasan Islands and the mainland; these must be also visited to help answer the question of contact with the mainland and mobility.

Only a handful of the sites visited have been dated and it is likely that there are both earlier and later sites which will alter our understanding of the timings and intensity of coastal exploitation on the islands. It would be useful to extend the program of test pitting to assess a wider range of sites in a broader range of shell mound groups. Tied into this further dating would be necessary and further development of the AAR technique to complement this.

The AAR technique needs further testing of the thermal regime which the deposits (and *S. fasciatus* shells) experience. This can be achieved by burying temperature loggers at various depths and in different sediments (including underwater) to determine temperature variation. Further radiometric dating samples would be needed to fully determine the extent of racemization and effect of burial at different depths.

Geoarchaeological investigations could also be expended; there are a number of areas which need further work to resolve their impact and relationship to shellfish exploitation. In the Khur Maadi older deposits may be located further into the interior of the in-filled bay. These may have been augered already, but dating funds were not available to test these. Likewise dating the micro-raised beaches or shell scatters located on top of these in Janaba West may shed light on the rates of change as well as the longevity of coastal exploitation in the region.

There is the potential to assess the seasonality of shellfish exploitation by examining thin sections of the shellfish, although this will also require an assessment of their lifecycle and growth rates. The preliminary isotope study showed a cyclical signal within both species; this shows that the method has potential, although again further work will be needed to determine what the signal is derived from (seasonal/tidal/climatic/etc). Further work could also focus on reconstructing climate from marine shell isotopes, if their signals could be disentangled (eg; Koike 1979; Deith 1983; Godfrey 1988; Kennett and Voorhies 1996; Milner 2001; Schulting and Richards 2002, 2009; Mannino *et al.* 2003, 2007; Van Neer *et al.*

2004; Milner *et al.* 2004; Milner 2005; Schulting *et al.* 2008; Hufthammer *et al.* 2010; Álvarez *et al.* 2011).

Following on along the isotope theme, human remains offer the possibility both to track movements and reconstruct diet (eg Choy and Richards 2009). Since only two degraded skeletons have been recovered, with only milk teeth present the options seem limited. However testing these for isotopic composition would make for interesting results, whether looking at the carbon/nitrogen to try to reconstruct diet, or strontium to try to determine whether large movements occurred during the individuals lifetimes.

Microstratigraphic analysis of deposits from within a shell mound would be a interesting theme, and one which is currently being developed by teams investigating sites in Tierra del Fuego (eg Vila *et al.* 2007; Briz *et al.* 2011). This could help to answer questions over the length of occupation events, short periods of abandonment, and even seasonality (eg Lucas 2008).

Future work might also focus on trying to assess modern and archaeological impacts on the Harid fish, currently being massively overexploited (eg Pitcher and Pauly 1998; Pauly *et al.* 2005). Assessing both time periods would make for an interesting comparison, and could even be linked with genetic work to try and identify bottlenecks in the past.

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Appendix

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Amino acid racemization dating of marine shells: A mound of possibilities

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Abstract

Shell middens are one of the most important and widespread indicators for human exploitation of marine resources and occupation of coastal environments. Establishing an accurate and reliable chronology for these deposits has fundamental implications for understanding the patterns of human evolution and dispersal. This paper explores the potential application of a new methodology of amino acid racemization (AAR) dating of shell middens and describes a simple protocol to test the suitability of different molluscan species. This protocol provides a preliminary test for the presence of an intracrystalline fraction of proteins (by bleaching experiments and subsequent heating at high temperature), checking the closed system behaviour of this fraction during diagenesis. Only species which pass both tests can be considered suitable for further studies to obtain reliable age information. This amino acid geochronological technique is also applied to midden deposits at two latitudinal extremes: Northern Scotland and the Southern Red Sea. Results obtained in this study indicate that the application of this new method of AAR dating of shells has the potential to aid the geochronological investigation of shell mounds in different areas of the world.

1. Introduction

Shell midden sites, found throughout the world, provide a range of important archaeological information, including the use of coastal resources, consumption practices and human impact on the environment. Shell middens are hard to define because they vary so greatly in size, content and form, but they are generally considered to be “a cultural deposit of which the principal component is shell” (Waselkov, 1987, p. 95). These deposits are especially common after the establishment of modern sea level in the mid-Holocene and have been recorded in their hundreds of thousands around the coastlines of the world, often forming large mounds containing many millions of shells. Earlier deposits are much less frequent, most probably due to Holocene sea level rise, resulting in the submergence of palaeoshorelines and associated archaeological evidence (Bailey and Flemming, 2008). However, earlier midden deposits are present in some areas of the world, often in deep cave sequences but also in occasional open-air locations. Middens from the Last Interglacial (Eemian) and before have been reported in Africa (e.g. Marean et al., 2007) and the Mediterranean (see Bailey and Milner, 2008), as well as on coastlines with steep offshore bathymetry or that have undergone tectonic uplift (e.g. O'Connor, 2007). The study of midden deposits, including their dating, must incorporate an accurate evaluation of the processes which have operated through time to produce the assemblages as they are observed today. Unfortunately, dating of these deposits can be problematic (e.g. Stein and Deo, 2003).

Radiocarbon dating is usually applied to develop chronological frameworks for shell midden deposits. It is a relatively costly procedure, so in most cases only a limited number of samples can be selected for dating; ideally these have to have an established provenance within a clearly identified stratigraphic sequence in order to produce reliable dating results for further interpretation. Shell middens, however, often do not meet these requirements. Often they accumulate relatively rapidly, within the margins of error of radiocarbon dating, or are subject to high levels of disturbance, mixing and inversion of materials, requiring

large sample sizes of dates to resolve issues of intra-site chronology (e.g. Glover et al., 1990; Stein and Deo, 2003).

Moreover, radiocarbon dating is complicated by factors such as the local spatial and temporal variation of the average global surface ocean marine reservoir effect (Stuiver and Braziunas, 1993; Ascough et al., 2005; Russell et al., in press). The source of the molluscan carbon, which partially depends on the feeding habits and metabolism of the molluscs (McConnaughey et al., 1997; Gillikin et al., 2005) and the possibility of mineral diagenesis (Taylor, 1987; Aitken, 1990) must also be considered.

In this context, a quick, cost-effective and (above all) reliable dating technique could be useful, allowing the processing of a large number of samples and an assessment of intra-site chronology and formation processes within shell midden deposits. We propose here intracrystalline protein geochronology on shell middens as a valuable “range finder” technique, providing qualitative relative age information, which could be calibrated by independent geochronology (such as radiocarbon). This could potentially be applied both to dating different layers within the same midden, when the temporal resolution is such that it is possible to resolve the internal stratigraphy, and also to correlate the age of different deposits on a regional scale (e.g. Bateman et al., 2008).

Amino acid racemization (AAR) dating of shell middens has a long history. As early as 1977, the Del Mar midden site (California) was targeted for AAR dating on *Chione* shells (Masters and Bada, 1977; Wehmiller, 1977). Masters and Bada (1977, 1978) compared the extent of isoleucine epimerization in radiocarbon dated shells and found distinct divergences. They attributed these to both inaccuracies in radiocarbon dating of carbonate and the isoleucine method on shell. Wehmiller (1977) showed that the shell radiocarbon and racemization data were consistent with shallow ground thermal effects. A third factor which was considered is the likelihood of sample mixing within the midden. Moreover, the possibility of burning and human-induced heating of edible molluscs is a general concern for AAR dating: exposure to high temperatures accelerates the degradation processes, resulting in high racemization values which are not indicative of the age of a sample. If unidentified, this could significantly affect the reliability of the technique in archaeological contexts (e.g. Masters and Bada, 1978). Recent work includes the application of the conventional methods of AAR dating to shell mounds in South Africa and Northern Spain (Bateman et al., 2008; Ortiz et al., 2009).

The present work involves the application of recently introduced methodologies of AAR dating to shell material (Sykes et al., 1995; Kaufman and Manley, 1998; Penkman et al., 2008), which have been successfully used to date Quaternary terrestrial and marine sediments in the British Isles (Parfitt et al., 2005; Penkman et al., 2007; Davies et al., 2009). The main advance is in the isolation of a fraction of amino acids (intracrystalline) from the shell which behave as a closed system during diagenesis. The extent of protein degradation within this system can be used as a secure indicator of the age of a molluscan sample. The analysis of the intracrystalline fraction therefore represents an important step forward for the reliability of AAR dating of mollusc shells (e.g. Rose, 2009).

This paper shows how the recent advances in the AAR dating method can be effectively applied to shell midden deposits. The examples presented come from a range of samples from Holocene sites in Scotland (Latitude: around 55-57° N) and the Red Sea (Latitude: around 16° N). Detailed temporal and stratigraphical information was not available for all sites, hindering the possibility of considering shallow temperature burial effects. These can be particularly important for middens where the samples have not been submerged during burial and where the length of time at high (shallow) ground temperatures can be large in proportion to the age of the sample (Wehmiller, 1977). Within this study it was not possible to investigate the effect of different within-site thermal environments during burial: our aim was to compare the extent of racemization between archaeological deposits of significantly different age, and in this pilot study we generally considered one layer for each site.

The recent methodological advances in AAR dating are briefly summarized and a series of tests recommended to obtain reliable AAR dating using the new closed system approach is proposed. We describe and suggest a protocol which may be applied to obtain preliminary information on the suitability of different molluscan taxa for further archaeological / chronological investigation of previously unexplored

areas. Finally, we test the reliability of the technique on archaeological material associated with independent chronological information, and we draw conclusions on the utility of AAR dating for the dating of shell midden deposits.

Our experiments investigate whether or not:

1. the taxa investigated (*Patella*, *Strombus*, *Tibia*, *Chicoreus*, *Trochus*, *Anadara*) retain an intracrystalline fraction of proteins;
2. the intracrystalline fraction behaves as a closed system with regard to protein diagenesis, both when artificially degraded via heating at high temperatures and in archaeological samples;
3. the new closed system approach of AAR dating can be applied to marine species from shell midden deposits;
4. AAR dating is able to discriminate between deposits of different ages within the Holocene;
5. exposure to high temperatures due to anthropogenic heating (e.g. to “cook” edible molluscs) affects the degradation rates of the intracrystalline proteins.

2. Amino acid diagenesis in a closed system

2.1 Background

A mollusc shell contains both a mineral and a protein fraction; the biochemical functions of proteins in the process of biomineralization have been widely investigated, but many aspects still remain unclear (e.g. Marin et al., 2007). After the death of the organism, the proteins undergo diagenesis: they break down to smaller fragments by hydrolysis and the single amino acids racemize and decompose. Here we use the term “protein” to indicate an original biomolecule (or a group of biomolecules) composed of a sequence of amino acids, which can be recovered from the biomineral upon death of the organism.

In some molluscan species, a fraction of the original proteins appears to be trapped within the mineral crystals and is thus protected from the external environment, forming a closed system (Penkman et al., 2008). Within this intracrystalline fraction, the extent of protein diagenesis is solely dependent on the thermal age of the fossil shells, i.e. the combined effect of time and temperature during burial upon the protein degradation reactions of the fossil shell. Conversely, the majority of the other proteins (intercrystalline) are not trapped in the crystals and therefore behave as an open system. The chemical isolation of the intracrystalline proteins is carried out by strong oxidation in sodium hypochlorite (bleaching) and complete removal of the intercrystalline component (Penkman et al., 2008; Demarchi, 2009).

The level of protein diagenesis is generally estimated by measuring the extent of amino acid racemization (AAR). Most of the amino acids can arrange their atoms in space in different configurations (called enantiomers) while maintaining their chemical properties: racemization is the reaction involving the transformation of one enantiomer into its non superimposable mirror image. When an amino acid differs from its mirror image, it is defined as a chiral amino acid. The majority of the natural amino acids possess at least one asymmetric carbon atom (a chiral centre), as a result of the four different substituents bonded to the alpha carbon. Amino acids with one chiral centre can exist in two non superimposable enantiomers, termed the L- (from the Latin *laevus*, laevorotatory or “left-handed”) and D- (from the Latin *dextro*, dextrorotatory or “right-handed”) forms. In living organisms, only L-amino acids are present, but they convert into their D-form after death; the ratio between the amount of D- and L- enantiomers (D/L value) will therefore indicate the time elapsed since death of a mollusc.

By analysing the extent of protein breakdown within the intracrystalline fraction, secure relative aminostratigraphies can be established for a series of molluscan samples: due to the progressive nature of diagenesis, the most degraded specimens are the oldest. This assumption is limited to: (i) closed system proteins; (ii) geographic areas which were exposed to the same climatic variations during the burial history of the fossil samples and (iii) monospecific samples, since different protein composition in different

molluscan genera has an effect on the degradation (racemization) rates (the “species effect”) (e.g. Lajoie et al., 1980).

2.2 Chiral amino acid analysis

Chiral amino acids from the intracrystalline fraction were detected following the method by Penkman et al. (2008). Here we briefly report the main steps used for sample preparation and the chromatographic analysis of multiple amino acids, performed with a modified method of Reverse Phase High Pressure Liquid Chromatography (RP-HPLC) of Kaufman and Manley (1998).

Each shell was sub-sampled for amino acid analysis, by snapping off a fragment of few square millimeters; for *Patella*, the edge of the shell was specifically targeted, to provide a consistent calcitic structural layer for analysis (Demarchi, 2009). Each shell fragment was first sonicated and rinsed at least five times in ultrapure water (18.0 mΩ), then air-dried and crushed with a quartz mortar and pestle. Powdered samples were weighed out (1-10 mg) and 50 µL 12% NaOCl (BDH) per mg of powdered shell was added at room temperature. The powders were left to soak for 48 h, and vortexed after 24 h to ensure complete penetration of the bleaching agent. The 48-h bleaching step is effective for isolating the intracrystalline proteins in a number of molluscan species (Penkman et al., 2008; Demarchi, 2009).

After the bleaching agent was removed by washing in ultrapure water (5 cycles) and methanol (1 cycle), the dry powders were further split into two subsamples. This allows the analysis for each sample of both the free amino acid fraction (“FAA”), representing the amino acids which are not protein-bound, and the total hydrolysable amino acids (“THAA”), representing both the bound and unbound amino acids.

For the analysis of the FAA, the subsamples were accurately weighed into sterile 2 mL glass vials and demineralised in 10 µL/mg cold 2 M hydrochloric acid (HCl) to dissolve the carbonate. Protein-bound amino acids are released by adding 20 µL per mg of sample of 7 M HCl to the bleached powder and hydrolysing at 110°C for 24 hours. All samples were dried in a centrifugal evaporator and rehydrated with 10 µL per mg of rehydration fluid, enabling quantitative analysis of the amino acids via RP-HPLC.

For analysis, we adopted a modified analytical method of Kaufman and Manley (1998) for an automated system of RP-HPLC, described in Penkman (2005), allowing the routine analysis of L and D isomers of 10 amino acids. A number of advantages result from the use of this modified RP-HPLC method. Firstly, the size of sample required is very small, < 2 mg. This can be crucial for the analysis of archaeological material, which is often scarce or too precious to analyse destructively using large samples. Secondly, the high automation of the system allows for maximum efficiency of the analysis, increasing the number of samples which can be processed, minimising the analytical variability and therefore improving the statistical significance of a given dataset. Moreover, it is possible to detect the enantiomers of multiple amino acids, thereby increasing the level of resolution available. This is a significant improvement from the conventional method of AAR dating, which generally focused on the racemization (epimerization) of a single amino acid, isoleucine (e.g. Miller et al., 1999). It has been reported that the D/L values of different amino acids exhibit a very strong co-variance (Goodfriend, 1991; Kaufman and Manley, 1998). It follows that unexpected differences in the DL ratios of some amino acids can be used to detect compromised samples (see section 4.3). The technique we propose is therefore cost-effective and efficient, and yields accurate quantification of multiple amino acids in the sub-picomole range. It is expected that the concentration of amino acids in the intracrystalline fraction would be lower than in the whole shell; therefore this method is highly appropriate for testing the ability of the bleaching treatment to isolate the amino acids from the intracrystalline fraction.

3. Isolation and testing of a closed system of amino acids in marine shells

3.1 Bleaching and leaching tests: rationale

Not all molluscs are suitable for closed system AAR dating and tests must be performed to investigate the behaviour of protein degradation in each taxon. In this paper we present results on six different taxa: *Patella*, *Strombus*, *Anadara*, *Tibia*, *Chicoreus*, *Trochus*.

Bleaching tests are done in order to optimise the efficiency of bleaching in isolating the intracrystalline amino acids (Penkman et al., 2008). Extensive bleaching and heating experiments on modern specimens were performed for *Patella* and a large database collected (Demarchi, 2009). Bleaching tests demonstrated that *Patella* retains a fraction of intracrystalline proteins which can be isolated by a 48-h bleaching step. The concentration of amino acids in bleached shells (~5 nmol/mg) represents about 13% of the original (unbleached) concentration (~38 nmol/mg) (Demarchi, 2009). The amino acid (THAA) concentrations are relatively high even after the matrix proteins are removed, allowing precise quantification via RP-HPLC without the interference of the background noise (generally, around 2- 10 pmol/mg). The effectiveness of 48 h bleaching in isolating the intracrystalline amino acids from *Patella* is in agreement with the data from other shell taxa analysed in the NEaar laboratory. A 48-h bleaching step was therefore adopted for *Strombus*, *Anadara*, *Tibia*, *Chicoreus* and *Trochus*.

The isolation of a fraction of intracrystalline proteins is critical for the use of molluscan material for reliable AAR dating, as a mollusc shell does not represent a closed system *per se* (Brooks et al., 1990). However, the behaviour of this fraction during long term diagenesis could be such that it is inappropriate to use it for dating purposes. High temperature (kinetic) experiments have traditionally been performed to monitor the behaviour of protein diagenesis, particularly amino acid racemization (AAR), within laboratory time scales (e.g. Hare and Mitterer, 1969). Heating experiments can be performed to test the closed system behaviour of the intracrystalline proteins from any molluscan species, and check whether leaching of the amino acids from the biomineral into the external environment occurs. The best strategy to enable quantification of the loss of amino acids from the system is to perform the heating experiments in an excess of water (Collins and Riley, 2000; Penkman et al., 2008): if the amino acids were contained within a closed system, no amino acids should be detected in the water used for the heating experiments.

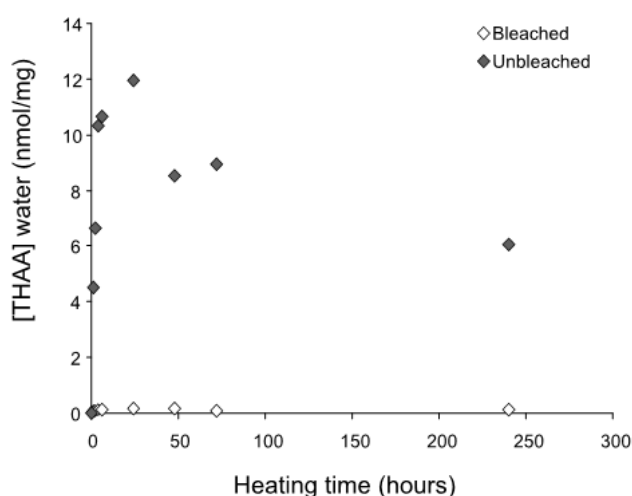


Fig. 1. Leaching of THAA amino acids into water from unbleached (whole shell) and bleached modern *Patella* shells upon isothermal heating ($T = 140^{\circ}\text{C}$). Note that unbleached shells lost up to 12 nmol/mg of amino acids into the water within the first 24 h of heating. On the contrary, the loss of amino acids from bleached shell powder is negligible.

A number of tests were performed to investigate the reliability of *Patella* for protein geochronology (Demarchi, 2009). These involved heating bleached and unbleached shell powder at 140°C and for different times (between 1 and 240 hours). The amino acid concentrations were measured for both the powder and the water to quantify leaching of amino acids from bleached/unbleached powders. For the bleached shells the concentration of amino acids in the water was similar to background levels. In contrast, the concentration of amino acids in the water for unbleached shells was one order of magnitude higher (nanomoles) (Fig. 1). This demonstrates that leaching is particularly marked for whole-shell (unbleached) *Patella*, which therefore does not represent a closed system. The implication is that the D/L values measured in unbleached shells would not necessarily be representative of the age of the mollusc, since such a permeable system is particularly prone to external contamination and to be affected by environmental factors (e.g. pH of the burial soil). On the contrary, the intracrystalline amino acids in *Patella*

approximate a closed system with regard to diagenesis, thus providing a robust substrate for reliable AAR dating (Demarchi, 2009).

3.2 A quick exploratory test for closed system behaviour of new species

Bleaching and heating experiments on modern samples are crucial for assessing the reliability of molluscan taxa for the closed system approach of AAR geochronology. However, such rigorous testing of each species is time consuming. This is a disadvantage when pilot data are required to assess the suitability or otherwise of different shell taxa, which have never been previously investigated for closed system AAR. This information is useful during archaeological excavations in order to optimise the sampling strategies on-site and to develop research plans which include a detailed AAR investigation of the deposits.

Here we describe the first application of closed system AAR dating to shell middens from a tropical area, the Farasan Island, Southern Red Sea. In order to test the suitability of the species available for the Red Sea middens, we devised a simple initial experimental test for closed system behaviour, which can be performed directly on archaeological shells from a site. We recommend that these tests should be performed routinely on new species of shells in order to provide an initial assessment of the potential of protein geochronology for each different taxon and site.

Five species of shells, from different midden sites and among the most abundant in the archaeological record in this area were targeted and the results obtained were used for informing further field sampling (see section 4.5): *Chicoreus* sp., *Tibia insulaechorab curta*, *Strombus fasciatus*, *Trochus dentatus*, *Anadara erythraeonensis*. These shells were collected from a group of middens located in an area north of the Harid bay, and are likely to be broadly contemporary based on their inland location and linear distribution (Williams et al., in prep.). *Chicoreus* shells were collected from a basal layer in the shell midden.

The bleached shells were heated at high temperature in sealed glass tubes under hydrous conditions to test for closed system behaviour. For each sample, ~20 mg of dry bleached powders were weighed into sterile glass ampoules and 300 µL of ultrapure water was added. The glass ampoules were sealed and placed in oven at 140°C for two different times (24 and 48 hours), with a “zero” time point (unheated). This was performed for each of the five taxa. Three replicates were prepared for each time-point.

After heating, 100 µL of the supernatant water was removed and analysed for the free amino acids (“FAAw” fraction; dried in centrifugal evaporator and rehydrated) and 100 µL was removed and analysed for the total hydrolysable amino acids (“THAAw” fraction; hydrolysed using 6 M HCl as no demineralisation of shell is needed, 20 µL per mg/equivalent). The heated powder was air-dried and separated into two sub-samples, for the analysis of the “FAA” and “THAA” fractions, performed following the analytical method detailed in section 2.

The main aim of the heating experiments was to test whether:

- a fraction of intracrystalline proteins exists within each taxon of shells and can be isolated via bleaching;
- the intracrystalline proteins behave as a closed system during diagenesis, by mimicking natural degradation with exposure to high temperatures. If this is the case, no leaching should occur; it is also expected that with increasing heating time, the extent of racemization (D/L) will increase, as well as the percentage of amino acids produced by hydrolysis of the peptide chain (free amino acids, FAA) and the extent of decomposition of certain amino acids (for example, serine into alanine) (Penkman et al., 2008).

3.3 Existence of the intracrystalline fraction

Tibia insulaechorab curta, *Trochus dentatus* and *Anadara erythraeonensis* showed very low concentrations of intracrystalline amino acids in the bleached powders, in both the FAA and the THAA fractions. The concentrations were comparable with background levels and, in most cases, fell below the limit of detection (Fig. 2a).

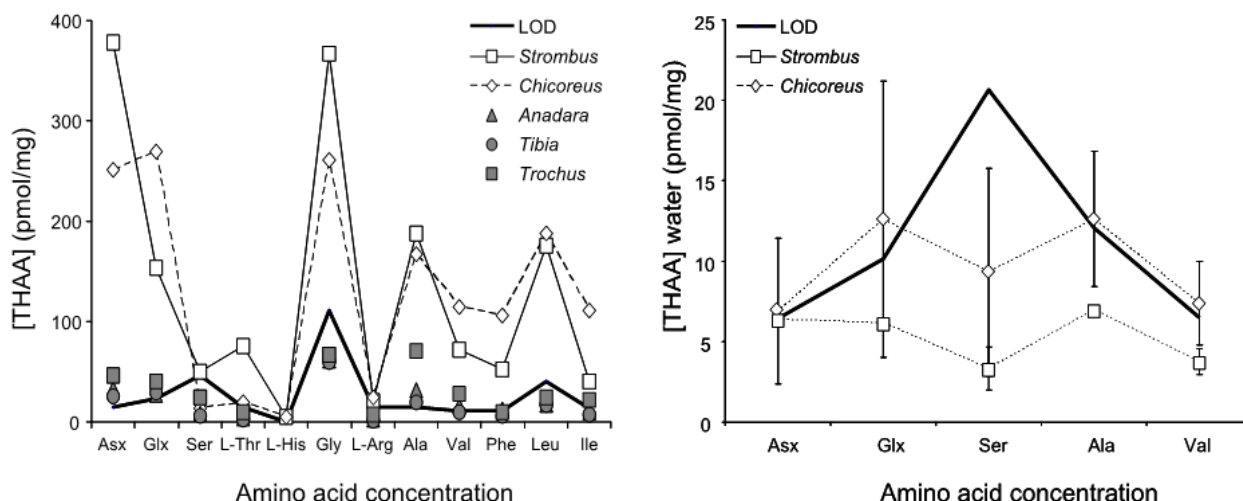


Fig. 2. (a, left) THAA concentration (powder) for unheated intracrystalline *Strombus*, *Chicoreus*, *Anadara*, *Tibia* and *Trochus* samples. Note that only *Strombus* and *Chicoreus* intracrystalline values can be considered significantly higher than the limit of detection. The Limit Of Detection (LOD) was calculated on the basis of the amino acid concentration detected in procedural blanks used in this study: $LOD = X_{blank} + k \cdot \sigma_{blank}$; where X_{blank} is the mean of the blank measures, σ_{blank} is the standard deviation of the blank measures, and $k = 3$. (b, right) Loss of amino acids in water for *Strombus* and *Chicoreus* after 48 h of isothermal heating at 140 °C, compared to the LOD.

The low protein contents detected may be due to the sampling strategy, as each shell was sampled only in a single location. It is therefore possible that this specific sampling area was enriched in mineral, but very poor in proteins, leading to the low amino acid concentrations observed. Further investigation of possible sampling strategies may help clarify this issue. The data recovered from *Anadara*, *Trochus* and *Tibia* were therefore not meaningful for the interpretation of intracrystalline protein diagenesis patterns. The results concerning the intracrystalline fraction within *Anadara* are particularly interesting, as this genus has been used in the past for traditional whole-shell AAR geochronology (e.g. Kimber and Griffin, 1987; Murray-Wallace et al., 1991). On the contrary, both *Strombus* and *Chicoreus* samples showed high concentrations of amino acids in the intracrystalline fraction and so were tested further (Fig. 2a).

3.4 Testing the closed system in *Chicoreus* and *Strombus*

The intracrystalline fraction isolated from *Chicoreus* and *Strombus* was tested for closed system behaviour via leaching experiments; for both species, the concentration of free and total hydrolysable amino acids detected in the water was only ~10 pmol/mg higher than background levels after 48 hours of heating at 140°C (Fig. 2b). No significant amounts of amino acids were leached out of the intracrystalline fraction, which therefore appears to behave as a closed system.

Further confirmation of the closed system behaviour of the intracrystalline proteins was sought by examining the diagenesis patterns by means of THAA vs FAA D/L plots (Fig. 3a) and “spider diagrams” (Fig. 3b) (e.g. O’Neal et al., 2000; Wehmiller et al., 2010). In a closed system, the extent of racemization measured in the FAA and the THAA fractions should be highly correlated. When the THAA D/L values are plotted against the FAA D/L values (Fig. 3a):

- a series of samples should fall on the same trendline;
- the less degraded samples should plot near to the origin of the axes, with progressively more degraded samples plotting towards the top right corner of the graph.

A sample falling outside the expected trajectory is likely to have been compromised (e.g. Preece and Penkman, 2005).

Spider diagrams are useful for testing the consistent behaviour of multiple amino acids within the system (Wehmiller et al., 2010): lines connecting D/L values measured on the same species should not cross and

the D/L values should increase with increasing heating time. This is the case for the amino acids which yielded the best chromatographic resolution and were therefore targeted for this study: aspartic acid/asparagine (Asx), glutamic acid/glutamine (Glx), alanine (Ala) and valine (Val) (Fig. 3b). Serine (Ser) follows unusual racemization patterns, with D/L values increasing very fast with increasing heating times, but then decreasing after a maximum, thus displaying an upward convex trend (Penkman et al., 2008; Demarchi, 2009). Therefore Ser was not included in the spider diagram in Fig. 3b. The racemization values for the species analysed were very high, as expected for an area of low latitude such as the Farasan Islands, where the higher temperatures would accelerate the reaction.

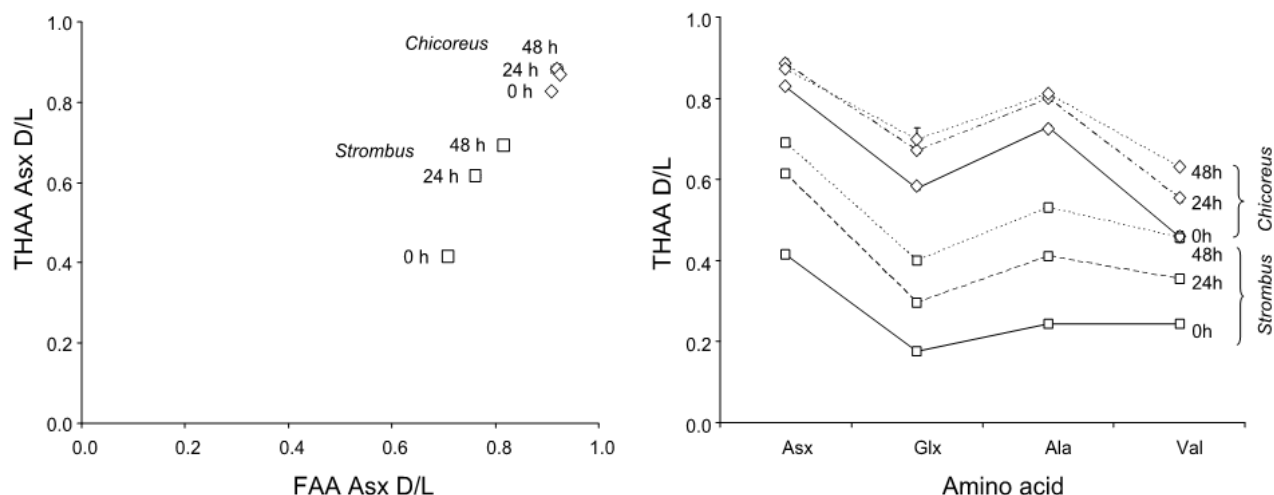


Fig. 3. (a, left) Asx THAA vs FAA DL ratio for *Strombus* and *Chicoreus*. Note the increase in D/L values for *Strombus* with increasing heating time, while *Chicoreus* Asx D/Ls cluster at higher values. Error bars represent one standard deviation around the mean. (b, right) “Spider diagram” illustrating the increase of THAA D/L values for Asx, Glx, Ala and Val with increasing heating time, for *Strombus* (square symbols) and *Chicoreus* (diamond symbols). Error bars represent one standard deviation around the mean.

It is expected that Asx would enable good levels of resolution for Holocene sites, due to its high racemization rates (Collins et al., 1999; Barbour Wood et al., 2006; Hearty and Kaufman, 2009). However, the high temperature experienced by Red Sea samples during their burial history limits the use of Asx as an age indicator at these latitudes. In unheated *Chicoreus* samples the Asx D/Ls were around 0.9, indicating that the reaction is approaching equilibrium. However, for *Strombus* the extent of racemization was lower (Fig. 3a and 3b), and a clear increase in both THAA and FAA D/L values was observed with increasing heating time. This could potentially be due to age differences between samples/midden sites (*Chicoreus* shells came from a basal layer within one of the middens), as well as taxon-specific protein degradation patterns. A tight relationship between the FAA and the THAA D/L values of the other amino acids could also be seen for *Chicoreus* and *Strombus*, thus confirming the closed system behaviour of the intracrystalline proteins from these two species (Appendix 1).

Two more protein breakdown indicators can also be considered when testing the behaviour of a molluscan species with regard to protein diagenesis: the percentage of free amino acids and the ratio between the concentrations of serine and alanine (Bada et al., 1978; Penkman et al., 2008). Both species analysed showed increasing percentages of free amino acids with increasing heating time, with *Chicoreus* displaying more extensive degradation (Appendix A). A net decrease in the [Ser]/[Ala] value could be observed for *Strombus* values, while *Chicoreus* seemed to have a slight (but not statistically significant; two-tailed t-test, SigmaPlot, v.11, $p = 0.552$) increase at higher heating times (Fig. 4). This is likely to be due to the decrease in analytical precision at the low concentrations of Ser (similar to background levels, see Appendix A) at these higher levels of protein decomposition, due to the exponential nature of diagenesis.

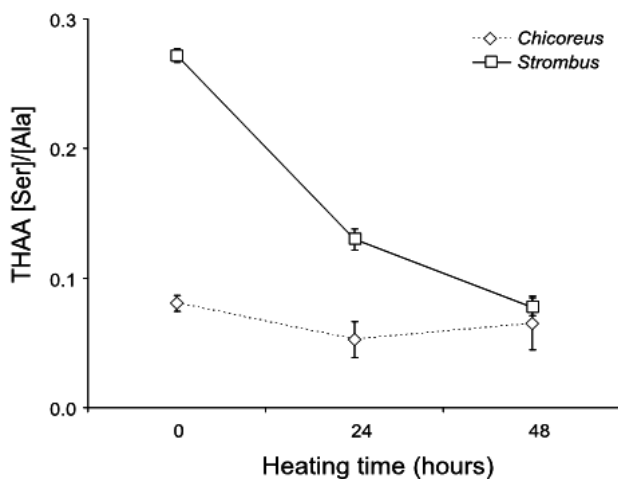


Fig. 4. Decrease of the THAA [Ser]/[Ala] value with increasing heating time, for *Strombus* and *Chicoreus*. This represents the decomposition of Ser into Ala with the progression of diagenesis. Note that the THAA [Ser]/[Ala] value for unheated *Chicoreus* is close to zero, thus indicating that this shell already displays a high extent of protein diagenesis. Error bars represent one standard deviation around the mean.

3.5 Conclusions on heating tests for the Red Sea

Bleaching and heating tests can be used as a quick, routine protocol to detect the most suitable shell substrate to be targeted for geochronological investigations of a new geographical and climatic area. Three out of the five taxa targeted for the Red Sea pilot study show very low protein content in the intracrystalline fraction: *Tibia insulaechorab curta*, *Trochus dentatus* and *Anadara erythraeonensis*. Since the amino acid concentration for these species is barely distinguishable from the background noise, the collection of these shells from archaeological sites for intracrystalline AAR studies is not recommended at this preliminary stage. However, further research may be able to clarify if this is a bias introduced by sampling in areas characterised by low proteic content.

The data recovered from *Strombus* and *Chicoreus* samples show significantly higher amino acid concentrations, closed system behaviour and a general pattern of increase in protein degradation (increase in D/L values, increase in percentage of FAA, decrease in [Ser]/[Ala]) with increasing heating time. They are therefore suitable for targeting for intracrystalline AAR dating. This initial assessment protocol thus provides useful information to aid the sampling strategies of excavations (section 4.5).

4. Archaeological tests

The bleaching and heating tests demonstrated that *Patella*, *Strombus* and *Chicoreus* retain an intracrystalline fraction of amino acids which behave as a closed system during diagenesis. These taxa were therefore used for the AAR investigation of shell-bearing archaeological deposits from two geographic areas: Scotland (UK) and the Farasan Islands (Saudi Arabia). The extent of protein degradation was compared with available independent age information. Because of the persistence of a species effect within the closed system as well as for the difference in thermal regimes between Scotland and the Red Sea, the extent of protein degradation can not be directly compared.

4.1. *Patella* from Scottish sites

Here we describe the results obtained on fossil *Patella* shells from different archaeological sites in Scotland. *Patella* specimens were analysed from two shell midden sites: Sand (Mesolithic) and Coire Sgamhadail 1 (Neolithic/Bronze Age) (Table 1) (Hardy and Wickham-Jones, 2009). Independent chronometric information was available, enabling the testing of the ability of closed system AAR to distinguish samples of different ages.

Site	Location	¹⁴ C age range	NEaar numbers	Fraction	Asx D/L	Ser D/L
Archerfield	Dirleton, East Lothian (66 NT 505 841)	1410 - 1445 cal AD	5419, 5420, 5421, 5422	bF	0.187±0.012	0.497±0.049
				bH*	0.151±0.004	0.217±0.006
Whitegate Broch	Caithness (ND 3541 6120)	880 - 1210 cal AD	5423, 5424, 5426	bF	0.270±0.009	0.543±0.062
				bH*	0.176±0.008	0.256±0.006
Coire Sgamhadail 1	Inner Sound, Western Ross (NG79063826, NG79063826)	2550-1880 cal BC	5505, 5506, 5507, 5508, 5509, 5510	bF	0.374±0.034	0.757±0.047
				bH*	0.210±0.015	0.331±0.032
Sand	Inner Sound, Western Ross (NG 6841 4934)	7050-6450 cal BC	5493, 5494, 5495, 5496	bF	0.515±0.063	0.840±0.027
				bH*	0.272±0.045	0.411±0.042
Sand (suspected heated)	Inner Sound, Western Ross (NG 6841 4934)	7050-6450 cal BC	5497, 5498	bF	0.836±0.011	n.d.
				bH*	0.728±0.024	n.d.

Table 1: Provenance of *Patella* samples analysed for AAR dating of shell deposits from Scotland: site name, location, independent age estimate range, number of samples analysed (each identified by a NEaar number), amino acid fraction analysed, Asx and Ser D/L values. Error terms represent one standard deviation around the mean for the site. Each sample was bleached (b), with the free amino acid fraction signified by 'F' and the total hydrolysable fraction by 'H*'.

Sand and Coire Sgamhadail 1 are two of the sites targeted in the *Scotland's First Settlers* project, a regional archaeological investigation of the Inner Sound, Western Ross (Scotland) (Hardy and Wickham-Jones, 2009). Sand is a rock shelter associated with a well-preserved shell midden which shows evidence for discontinuous human occupation from as early as the late 7th millennium BC to the Neolithic. Samples analysed for AAR dating (courtesy of P. Ascough, K. Hardy and C. Wickham-Jones) come from layer B24A NE spit 5. This layer is bracketed by two radiocarbon dates (Ascough et al., 2007; Hardy and Wickham-Jones, 2009):

- 7050 to 6500 cal BC (OxA-10384): obtained from ¹⁴C on a bevel-ended bone artefact BT03 from Spit 4, retrieved from a loose unconsolidated limpet midden overlying a rockfall and covered by crushed shell and turf;
- 7050 to 6450 cal BC (OxA-12096): obtained from ¹⁴C on a second bevel-ended bone artefact, BT30, from sample B25B NE Spit 7 collected from the same limpet midden.

The overall age span for the AAR samples is therefore 7050-6450 cal BC.

Coire Sgamhadail1 has a small assemblage of shells and cultural material. Two radiocarbon determinations have been reported (Hardy and Wickham-Jones, 2009):

- the first obtained from a piece of hazel charcoal found in a cave shell midden, Test Pit 1, context 8914 (2550 to 1950 cal BC, AA-50692)
- the second from an ungulate bone securely stratified in the same shell midden, Test Pit 1, context 8914 (2290 to 1880 cal BC, AA-50693)

For the purpose of this study, it was therefore assumed that the site age ranged between 2550 and 1880 cal BC.

Two sites of historic age were also considered. Although not shell midden sites, as defined above, they do contain samples of the same taxon that allows the technique to be tested on younger material.

Samples NEaar 5419-5422 (Table 1) come from Archerfield, a recently discovered “lost” medieval village in the East Lothian. Currently unpublished, it represents one of the rare rural medieval settlements found in Scotland. *Patella* specimens from Archerfield were dated directly at the East Kilbride radiocarbon facility alongside contemporary terrestrial carbonised plant material for investigations regarding the marine reservoir effect (MRE). The terrestrial samples (SUERC19680-81, SUERC19685-90) yielded a mean date of 490 ± 25 BP, corresponding to a calibrated date range of 1410 – 1445 AD at 95.4% confidence (atmospheric data from Reimer et al., 2004; Oxcal v 3.10 Bronk Ramsey, 2005; Russell et al., in press).

Whitegate Broch in Caithness was excavated as part of The Caithness Broch Landscapes Project in 2002, with the first stage focusing on the re-survey and excavation of broch settlements (circular hollow-walled buildings, commonly found in Scotland) examined by Sir Francis Tress Barry in the second half of the nineteenth century (Anderson, 1901). Excavations in 2006 provided sample material including shell and animal bone from the interior of the broch structure (Heald and Jackson, 2001). *Patella* shells were radiocarbon dated for MRE investigations at SUERC alongside contemporary terrestrial herbivore bones. The bone material provided a mean date of 1370 ± 70 BP, which calibrated to a calendar age range of 880 – 1210 AD at 95.4% confidence (Russell, unpub. data) using Oxcal v. 3.10.

4.2 Racemization results for the Scottish sites

For shells which have undergone diagenesis in the burial environment, the extent of racemization within a closed system of proteins should be directly related to the age of the fossil sample (Penkman et al., 2008).

Archaeological *Patella* samples from the Scottish sites detailed in section 4.1 were analysed and the DL ratios of multiple amino acids represented on FAA vs THAA plots, as described for the heating experiments on *Strombus* and *Chicoreus* (Fig. 3a). All values fell on a trendline for Asx (Fig. 5a) as well as Ser, Ala, Glx, and Val (data not shown), thus satisfying the first condition for closed system behaviour. All the amino acids considered displayed the expected increase in DL ratios with increasing age when THAA and FAA D/L values for each subsample were compared to independent geochronological information (Table 1, Fig. 5a, 5b, 5c). However, not all the amino acids allow the same resolution over different timescales. Different amino acids racemize at different rates as a function of their molecular structure, position in the protein chain, flanking residues and status (free or bound) (e.g. Kriausakul and Mitterer, 1980). Ser and Asx are among the fastest racemizers and will therefore give better resolution over Holocene timescales (Fig 5b and 5c). The fast racemization rates of Asx have been successfully used to date young samples in both warm (Goodfriend, 1992; Barbour Wood et al., 2006; Hearty and Kaufman, 2009) and cold (e.g. Goodfriend et al., 1996) climates. Data obtained in this study confirm the possibility of applying the technique for extremely young samples, even at the low burial temperatures experienced by the shells in Scotland.

Samples from Archerfield and Whitegate could be distinguished on the basis of Ser and Asx THAA and FAA DL ratios (Fig. 5a, 5b, 5c). The Mesolithic and Neolithic/Bronze Age shell middens of Sand and Coire Sgamhadail1 can also be separated on the basis of the D/L values measured in *Patella* (Fig. 5b, 5c), as well as the decomposition rate of Ser into Ala (Appendix 1). However, the variability of the data was higher in these contexts. This is unsurprising and it is likely to be due to the extremely complex depositional patterns of midden deposits. Mixing can affect the sample’s deposition even at small scales, causing adjacent shells to yield different D/L values. Also, the effect of variable thermal environments must be considered, as shell midden samples may have been exposed to solar radiation and natural heating during shallow ground burial (Wehmiller, 1977). Here we considered only a single layer for each site and therefore it was not possible to assess the effect of shallow burial thermal environments in detail. However, we are undertaking a comprehensive study of a single shell midden in Skye, Scotland, which will provide the data to investigate these issues further. Other studies (e.g. Barbour Wood et al., 2006) have reported better age resolution for other biominerals using the racemization of aspartic acid than the one we observe for these Scottish shell middens. However, these were undertaken in significantly warmer latitudes: the colder burial temperatures experienced by the Scottish *Patella* shells decelerate the racemization rate significantly, with a consequent loss in resolution.

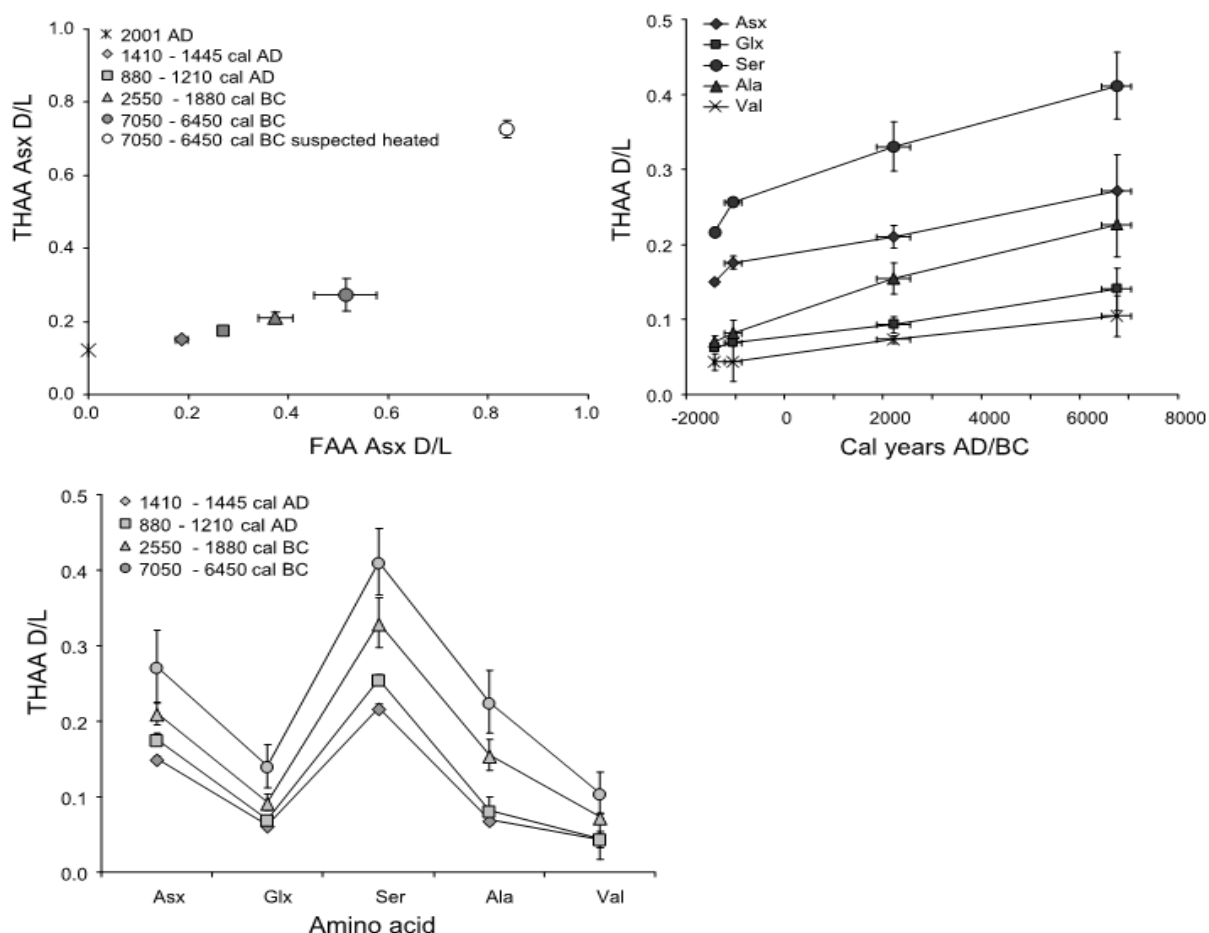


Fig. 5: (a, top left) FAA vs THAA plot for Asx D/L measured in Scottish archaeological *Patella*; error bars represent one standard deviation around the mean for each site. Modern (collected in 2001 AD) *Patella* D/L values are also plotted for comparison. (b, top right) Asx, Glx, Ser, Ala and Val THAA D/L values measured in Scottish archaeological *Patella* plotted against the age of each site. Error bars represent age uncertainty on the x-axis and one standard deviation around the mean of D/L values for each site on the y-axis. (c, bottom left) “Spider diagram” illustrating the increase of THAA D/L values for Asx, Glx, Ser, Ala and Val with increasing age of the archaeological deposit. Note that different amino acids have different resolving powers over different timescales. Error bars represent one standard deviation around the mean.

4.3 Anthropogenic heating detected?

One problem which may affect AAR dating of edible shells is the common practice of food processing, which may involve heating (Masters and Bada, 1977; 1978), thereby inducing protein degradation unrelated to the age of the sample. Detecting whether a shell has been exposed to very high temperatures is of the utmost importance, as not doing so may result in misleading conclusions on the age range of a sample. If only a few samples are analysed from a midden site where the likelihood of anthropogenic heating is high, and no comparative concentration data are available for the shell taxon analysed, the DL ratios alone may result in an overestimate of the age of the heated specimens.

Having identified heating (burning in campfires or brush fires) as being the probable source of anomalous D/L values in archaeological ostrich eggshells, Brooks et al. (1991) performed a series of heating experiments and described the resulting sequence of changes in amino acid composition and concentrations. In particular, 1 hour of dry heating of ostrich eggshell at 200°C – 280°C caused the amounts of aspartic acid, glycine and alanine to decrease with respect to the unheated composition. Serine, threonine and arginine were either only detectable at trace levels or had disappeared completely, while the concentration of glutamic acid remained relatively constant (Brooks et al., 1991).

Anomalous D/L values were found for two of the samples from Sand, which differ from other values from the same site. These did not appear macroscopically “burnt” or charred. However, when the compositional data are considered (Fig. 6a), a similar pattern to that described by Brooks and colleagues is shown, especially regarding the decrease in aspartic acid, serine and arginine. We are currently carrying out heating experiments at 280°C on bleached *Patella*. Preliminary results appear to confirm the same trend as observed on ostrich eggshell. On the contrary, other *Patella* samples analysed in the NEaer laboratory, from a ~250 ka raised beach deposit in Northern England, show a “normal” concentration profile, different from the “suspected heated” samples (Demarchi, 2009). This indirectly confirms that the D/L values of two of the Sand samples had been artificially raised by heating and do not represent real age differences. The chromatograms for “suspected heated” samples also show a striking difference when compared to “normal” samples, displaying not only the relative compositional differences described above, but also the presence of a number of other peaks which do not correspond to known standards. These peaks are postulated to be peptide / amino acid degradation products and could potentially be identified using mass spectrometry.

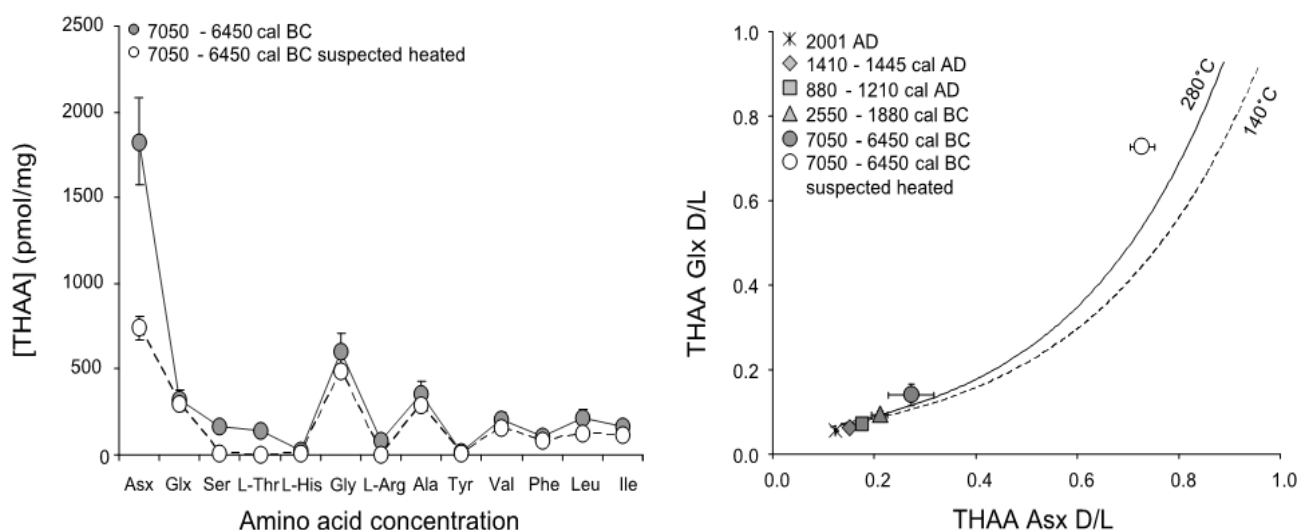


Fig. 6: (a, left) THAA amino acid composition for unheated and “suspected heated” Sand samples. Error bars represent one standard deviation around the mean. (b, right) THAA Glx vs THAA Asx D/L plot for unheated and “suspected heated” Sand samples. The trendlines for heating experiments at 140°C and 280°C, performed on modern *Patella* (Demarchi, 2009), is also reported: note that the “suspected heated” samples from Sand fall on a different trajectory, possibly indicating different diagenetic pathways induced by exposure to very high temperatures due to fire.

Moreover, samples which we suspect were exposed to very high temperatures could be easily recognised on a plot of THAA Glx D/L vs THAA Asx D/L (Fig. 6b). Glx and Asx D/Ls should covary very strongly; a plot of Glx vs Asx D/L is able to identify aberrant results and can therefore be used as a criterion for screening results in AAR studies (Kaufman, 2006). The Sand “suspected heated” samples fall off the trajectory of both archaeological and modern *Patella* heated at 140°C (Demarchi, 2009). However, our preliminary data for the heating experiments at 280°C fall on a trajectory which approaches more closely that of the Sand samples (Fig. 6b). We believe this is due to the fact that different diagenetic pathways are followed by the proteins at the relatively low temperatures of our kinetic experiments at 140°C compared to the significantly higher temperatures when exposed to fire. These can easily reach 500 °C and above, although such temperatures have been observed to induce charring of bone (Brain and Sillen, 1988). The data from the *Patella* heated at 280°C show a trend towards that of the “suspected heated” Sand sample, supporting our hypothesis. The identification of anthropogenic heating is especially important for shells not appearing macroscopically “burnt” or charred, since it provides evidence on the use of fire on a site.

4.4 Conclusions for Scottish shell middens

Overall, given that suspected heating appears to be identifiable, amino acid data from *Patella* shells provide a relatively simple method for distinguishing Holocene deposits on the basis of their mean DL ratios. The best amino acids to target for dating sites younger than 12 ka are the fast racemizing amino acids such as Ser and Asx: the D/L values measured over a range of Holocene shells were able to correctly discriminate these deposits of different ages. The resolution obtained was surprisingly good for historic samples of Whitegate and Archerfield, which differ in age by only a few hundred years. The two midden sites of Coire and Sand could also be distinguished on the basis of the extent of racemization as well as the [Ser]/[Ala] values. The resolving power of the technique is less for these older sites, mainly due to the higher natural variability of the data. This is likely to be due to sample mixing within the shell midden and shallow ground burial temperature differences. However, the two sets of data fall in two definite clusters on a THAA vs FAA plot, and can therefore be distinguished.

This has important implications for the archaeological application of AAR dating to shell midden deposits in Scotland, where the high concentration of mounds implies that radiocarbon can not be used feasibly as a “range finder” technique. This study has demonstrated that AAR can be used as a “screening” method, to build relative chronological frameworks and group the deposits in broad age ranges. Radiocarbon can then provide absolute age information to calibrate the relative framework.

4.5 Testing the Red Sea shell middens

Shell middens were first systematically recorded in the Farasan Islands, southern Red Sea, only in 2006 (Bailey et al., 2007). Over 1500 shell midden sites have been found on the main islands of the Farasan archipelago, distributed in ten large concentrations (Williams, in prep). The islands are c. 40 km from the Saudi mainland, implying that those responsible for the formation of the midden sites must have been competent in sea travel. Little archaeological work has been undertaken on the islands, and the origin and extent of these deposits remains unclear. Preservation of the sites is excellent, owing to a combination of environmental factors and the current low population density on the islands.

Site	Location	¹⁴ C age	NEaar	Fraction	Asx D/L	Glx D/L	Ala D/L
JE0004	Janaba Bay East - Base of the midden	3519-3126 cal BC (BETA-267671; <i>Chama reflexa</i>) ¹	5744- 5753	bF	0.835±0.030	0.568±0.034	0.810±0.054
				bH*	0.689±0.053	0.446±0.038	0.673±0.056
KM1057	Khur Maadi bay - Base of the midden	3641-3372 cal BC (BETA-255384; <i>Chama reflexa</i>) ¹	5754- 5763	bF	0.880±0.021	0.586±0.043	0.800±0.038
				bH*	0.744±0.030	0.450±0.032	0.683±0.031
KM1367	Khur Maadi bay - Base of the trench	1520-1270 cal BC (BETA-255386; <i>Anadara erythraeonensis</i>)	5262- 5265 5486- 5489	bF	0.846±0.027	0.481±0.058	0.757±0.064
				bH*	0.640±0.058	0.352±0.031	0.576±0.047

Table 2: Provenance of *Strombus* samples analysed for AAR dating of shell deposits from the Red Sea: site name, location, specific layer, independent age estimate, number of samples analysed (each identified by a NEaar number), amino acid fraction analysed, Asx, Glx and Ser D/L values. Error terms represent one standard deviation around the mean for the site. Each sample was bleached (b), with the free amino acid fraction signified by ‘F’ and the total hydrolysable fraction by ‘H*’. Radiocarbon¹ dates were obtained on marine shell and adjusted for local marine reservoir effect of 110±38yr (Stuiver and Reimer, 1993).

Strombus fasciatus proved to be present in most shell mounds across the islands, and it was selected for further testing to determine the extent to which the temporal resolution of sites could be assessed. Given the scale of the preserved deposits, excavation focused on two sites on the main island, both of which are at risk due to development activities.

Independent radiocarbon age information was obtained for these two sites and AAR analyses undertaken on the intracrystalline proteins from *Strombus fasciatus*. AAR samples from KM1057 and JE0004 were taken directly from sections exposed during excavation, assuring their stratigraphic integrity, and adjacent to the respective radiocarbon dating samples (3641-3372 cal BC and 3519-3126 cal BC, respectively: Table 2). A third sample for protein geochronology was taken from the base of a geoarchaeological trench (designated KM1367), excavated in the centre of the in-filled Khur Maadi bay, which had yielded younger radiocarbon ages (1520-1270 cal BC: Table 2). Unfortunately, radiocarbon determinations were not performed on the same samples used for AAR dating. Therefore, the possibility that the radiocarbon ages may not be representative of the age of the shells targeted for amino acid analysis can not be excluded. However, for the purposes of this study we assumed that little or no sample mixing had occurred within the layers.

Ten *Strombus fasciatus* shells were sampled from each context and analysed bleached according to the protocol described in section 2. These were used to test the resolution of the method, and assess the extent to which AAR could be used to distinguish between deposits of different age in this area.

A plot of THAA Glx D/L vs THAA Asx D/L showed that all the samples fall on a coherent trajectory of increase in the extent of degradation, thus confirming the good closed system behaviour of the intracrystalline fraction. Samples from JE0004, KM1057 and KM1367 displayed a higher extent of protein degradation than the unheated “test” *Strombus* samples (Fig. 7a). This was also confirmed when Asx, Glx, Ala and Val THAA D/L values were considered (Fig. 7b). This provides a maximum age for these specimens, indicating that the test samples are younger than 1520-1270 cal BC.

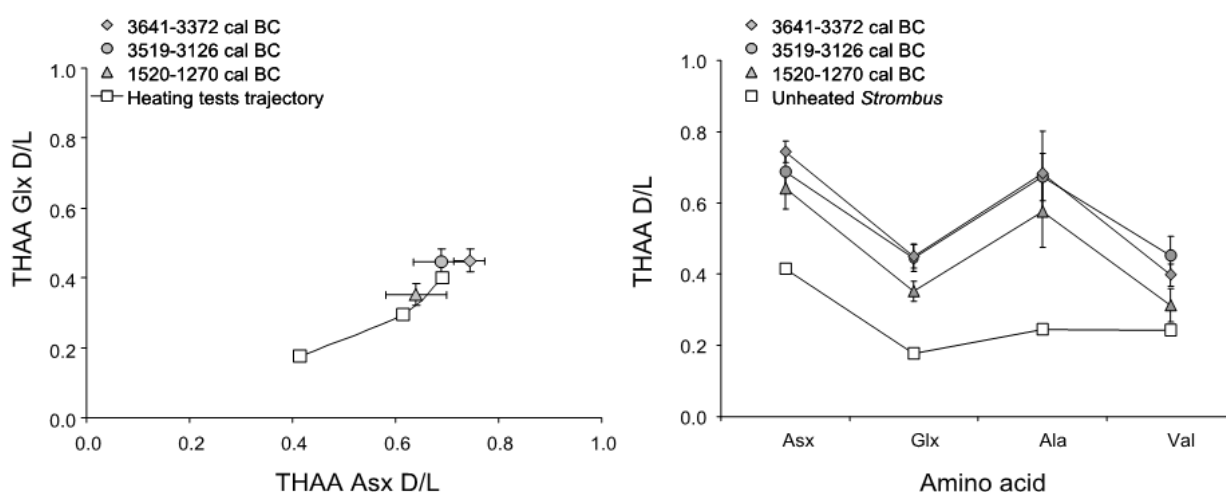


Fig. 7: (a, left) Glx vs Asx THAA D/L plot for *Strombus* samples investigated for the closed system test (white symbols) and for the archaeological applications on the Farasan island shell middens. Note that all samples fall on a coherent trajectory of protein degradation. Error bars represent one standard deviation around the mean. (b, right) “Spider diagram” for archaeological and “test” unheated *Strombus* shells from the Farasan Islands comparing the THAA D/L values for Asx, Glx, Ala and Val with the calibrated ^{14}C ages of the archaeological layers.

Data from JE0004 and KM1057 are indistinguishable within one standard deviation around the mean for each site. This is consistent with the radiocarbon ages, and it suggests near-contemporaneous deposition of the two layers. KM1367 showed lower levels of protein degradation for Asx, Glx, Ala and Val (Fig. 7a and 7b), indicating that this layer is likely to be younger, again in agreement with the radiocarbon dates.

However, the difference is very small; Glx and Val are the only amino acids for which this difference is not within one standard deviation. Glx and Val racemization rates are generally lower than for Asx and Ala, therefore these amino acid have good potential for enabling age resolution of samples at these latitudes and within this time interval.

4.6 Conclusions on the Red Sea

Both heating tests and the comparison with absolute radiocarbon dates showed that the new methodologies of AAR geochronology have the potential to be applied to the dating of shell midden deposits in tropical areas, where high temperatures prevail, such as the Farasan Islands. Further analyses are being undertaken to determine the extent to which this method can be used to distinguish between sites of different age at a broader temporal scale. Tests for the effect of anthropogenic high-temperature heating, similar to that described in section 4.3, are also being performed, as Site JE0004 had a sequence of hearths (Williams, in prep). The effect of short-lived heating on these shells is not known at present, but will be the subject of future investigations.

5. Conclusions

This study is the first application of the new methodologies of closed system protein geochronology to shell midden deposits. Two main areas were investigated, from contrasting climate zones: Scotland and the Red Sea. Results obtained showed that the technique has the potential to resolve samples of differing age within Holocene deposits in both areas. The tropical temperatures accelerate the rate of protein degradation, precluding direct comparison of the D/L values between samples experiencing very different integrated temperature histories. A possible method for detecting anthropogenic heating of shell samples was also highlighted, potentially helping to detect past exposures to fire.

A relatively simple and quick screening protocol for testing the suitability of molluscan species for AAR dating was described. This test provides a useful tool to inform sampling strategies in the field, demonstrated here by the application to the Red Sea material.

In conclusion, closed system protein geochronology has the potential to be used as a rapid range finder dating technique for shell midden deposits, and is also a reliable and cost-effective alternative to radiocarbon dating for investigating the chronological variability within large clusters of deposits. Where surveys like the Scotland's First Settlers Project and the Farasan Islands Project have identified large numbers of new sites which need to be dated in order to be interpreted, AAR dating provides a quick reliable method for relative geochronology.

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